STUDIES ON THE PRIMARY PRODUCTION IN THE INDIAN SEAS

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This is to certify that this Thesis is an authentic record of the work carried out by me at the Central Marine Fisheries Research Institute and that no part thereof has been presented before for any other degree in any University.

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PREFACE

The measurement of the photosynthetic fixation of carbon by the plankton algae in the aquatic environment has been an important investigation extensively undertaken in many parts of the world during the last two decades. Though technically it is possible to estimate the productivity by several methods, the oxygen and radioactive carbon techniques have been mainly used for collecting field data both from fresh and marine waters. The candidate has been engaged in studies on primary production since 1957, when the Central Marine Fisheries Research Institute, with which he is associated, initiated a programme of research at Mandapam on the south-east coast of India.

A planned programme of research for over four years conducted in the inshore waters of Mandapam showed that this region has a remarkably high rate of production during a greater part of the year which sustains a rich and variegated fauna including luxuriant coral reefs and fishes. Values comparable to the highest rates of primary production measured anywhere in the marine environment were recorded from some inshore stations during periods of high phytoplankton production.

A reliable standardisation of stock solutions of ^{14}C and the counting equipment is an essential pre-requisite in order to get comparable and meaningful values in primary production measured by ^{14}C technique. During the spring of 1964 the candidate spent some time in Copenhagen with Prof. E.Steemann Nielsen at the Botanical Laboratory of the Danish Pharmaceutical Institute, where he got acquainted with the experimental methods and biological standardisation of ^{14}C. Cultures of Chlorella brought by him from Copenhagen were developed at Mandapam for biological standardisation of the stock solutions made in the country. In the course of a comparative study of the different methods of standardisation, he obtained Millipore filters laden with thin layers of radioactive plastic, from Dr. H.R.Jitts of Commonwealth Scientific and Industrial Research Organisation, Australia. Standardisation and calibration were carried out with a windowless gas flow proportional counting system, developed by the Electronics Division of the Atomic Energy Establishment (now Bhabha Atomic Research Centre), Bombay and a liquid scintillation counter at the Radiochemistry Division of the Centre. The candidate obtained almost identical values with the biological and scintillation methods. Inter-comparison of values obtained with the stock solution and counter at the Institute was made with those of the International Agency for ^{14}C Determination at Charlottenlund and C.S.I.R.O. Australia from parallel in situ experiments. These efforts helped him a long way in obtaining comparable and more accurate results in his studies.

From 1965 the candidate has been involved in productivity measurements along the west coast of India and the Laccadive Sea.

As the need for utilising the primary production data for estimating the living resources and the potential yield was felt, the candidate undertook a study of the primary production of the Indian Ocean, in general, for which some data collected by the participating ships in the International Indian Ocean Expedition were used. On the basis of this it was possible to make a quantitative assessment of the potential resources.

Short-term studies on some special types of ecosystems have also been made during the course of the candidate's work. After a devastating cyclone along the south-east coast of India in December 1964, several low-lying areas were inundated and were teeming with diverse organisms. It was a unique type of ecosystem with oceanic forms of phytoplankton temporarily occupying land-locked pools with fast changing environmental conditions and succession patterns. Besides, productivity of the mud banks along the Kerala coast and the coral reefs in the south-east coast, Minicoy and Andaman Islands were also studied for short periods. The growth kinetics of the mixed populations of phytoplankton and some selected species under natural conditions and of a laboratory culture of a green flagellate, *Tetraselmis gracilis* Kylin, were also undertaken which form the first ever observations of similar nature from here. The study of the seasonal variation of the different phosphorus fractions in relation to primary production and total organic nitrogen of the particulate matter are also studied for the first time.

The studies conducted by the candidate during a greater part of the last seventeen years as a member of the staff of the Central Marine Fisheries Research Institute, have been oriented toward an assessment of the potential resources in the seas around the Indian Peninsula. These investigations were the pioneering ones from the Indian seas and from the time of initiation, efforts have been made to refine the technique and approach to the problem. These studies have, in a large measure, added to the understanding of the primary productivity in the Indian seas.

The candidate is indebted to Dr.R.Raghu Prasad, now Assistant Director General, Indian Council of Agricultural Research, New Delhi, who put him on to these studies and for his guidance during the major part of the work and also for his continued interest and encouragement.

The successive Directors of the Institute, Dr. N.K. Panikkar, Dr.S.Jones, Dr.S.Z.Qasim and Dr. R.V.Nair extended all facilities and encouragement to the candidate in carrying out this work. The late Dr. V.K.Pillai, then Director, Central Institute of Fisheries Technology and Mr. S.K.Banerji, now in FAO, Rome, gave several suggestions in chemical oceanography work and in the estimation of potential resources. Prof. C.V. Kurien, Dean of Marine Science, Cochin University and Dr. E.G.Silas, Head of the Division of Marine Biology and Oceanography of this Institute gave constant help and encouragement in the preparation of the thesis. Messrs. K.J.Joseph, V.K.Balachandran and C.P.Gopinathan, his colleagues in the section extended their whole-hearted co-operation both in the field and in the laboratory. Dr. G.S.Sharma and Mr. D.S. Rao and several other colleagues in the Institute have been helpful with many suggestions.

Dr.H.R.Jitts (Australia) had given the radioactive Millipore filters for the standardization of the counter and rendered valuable help in the work connected with it. The candidate wishes to thank each one of them.

The candidate expresses his immense gratitude to Prof. E.Steemann Nielsen, the doyen of primary production research, for the many courtesies and valuable suggestions received ever since the beginning of this work. His prompt response on every occasion has been a constant source of inspiration and guidance.

INTRODUCTION

All the earlier investigations concerning productivity of the Indian seas were based on the standing stock of phytoplankton taken with tow nets. Although considerable information was available on such standing crop measurements, no data were available on the production of organic matter *per se*, when these investigations were initiated in 1957 in the inshore waters of Mandapam, along the south-east coast of India.

The word production has been used synonymously with standing crop. But there is a sharp distinction between the two, though in nature there is rather a high correlation between the standing stock of phytoplankton and primary production. Primary production represents the quantum of organic matter produced by the planktonic algae and the benthic flora utilising the light energy from the sun and the nutrients in the environment. Since it initiates the whole marine food chain which terminates in the larger fishes and sea mammals, this study provides a useful basis for an assessment of the potential yield of fishery resources.

To begin with, the well-known light and dark bottle technique formed the basis for the measurements. Later with the availability of carbon-14 from the International

Agency for ^{14}C Determination, Charlottenlund, Denmark, data were collected from different regions in the Gulf of Mannar and Palk Bay along the south-east coast of India. A systematic study extending over a period of four years yielded very useful information on the production of organic matter and based on this an assessment of the potential resources in the inshore waters of the Gulf of Mannar was made. Gradually with the procurement of counting equipment and radio-isotope of carbon from the Atomic Energy Establishment, Trombay, Bombay, studies were extended to the south-west coast of India and the Laccadive Sea. During the International Indian Ocean Expedition a large amount of data was collected by the participating countries on primary production and the environmental phenomena that regulate it from different regions of the Indian Ocean, the results of which are being published. But data from the inshore and offshore regions of the Indian Peninsula are lacking. These studies, thus, form a major complement to the investigations on the primary production of the Indian Ocean from a vitally important sector, where there is much seasonal and geographical variability.

The results presented here in ten chapters are based on the candidate's work from 1957 along the south-east and south-west coasts of India and the Laccadive Sea.

Chapter I contains the introduction and historical resumé in which the development of methods of estimating primary production till the ^{14}C technique was introduced and the subsequent controversy have been briefly reviewed along with the work carried out in the Indian seas.

In chapter II on the environment, a short description of the areas along the south-east and south-west coasts of India, where the investigations were mainly carried out, has been given together with the hydrological conditions and the plankton characteristics of the area.

Chapter III, on materials and methods, contains details of the techniques employed. A critical appraisal of the methods of standardisation, intercalibration trials with different stock solutions of ^{14}C and a comparison of the results obtained by the two techniques have also been included in this chapter which form a necessary adjunct for a proper evaluation of the results.

Chapter IV deals with the seasonal and quantitative variations of the common phytoplankters and the general growth kinetics of the total population and some selected species. Growth trend and productivity characteristics of a green flagellate, Tetraselmis gracilis, in culture have also been presented in this chapter.

Chapter V gives the seasonal and regional variations in primary production in the different areas such as inshore and oceanic waters of the Indian seas. The daily rate of production and the magnitude of annual production in the Gulf of Mannar, Palk Bay, west coast of India, the Laccadive Sea and the mud bank south of Alleppey are dealt with and in addition, an account of the productivity of the Indian Ocean in general, is included based on available data.

Chapter VI deals with the factors influencing primary production. Section 1 deals with the measurements of light penetration and the depth of the euphotic zone in the different regions of the Indian seas. Section 2 contains the variations of the common nutrients such as phosphate, nitrate and silicate during the summer months preceding the monsoon, periods of south-west monsoon and post-monsoon months. Sections 3 and 4 deal with the relationships of the standing crop of phytoplankton as estimated by cell counts and chlorophyll, and of numerical abundance of zooplankters in a shallow area of the Gulf of Mannar.

Chapter VII deals with the different phosphorus fractions in relation to primary production in the Gulf of Mannar. Chapter VIII contains results of investigations on total organic nitrogen (converted into protein equivalent) of the particulate matter studied in conjunction with primary production for over an year in the Gulf of Mannar.

Chapter IX contains a review of the primary productivity of world oceans to demonstrate the comparative rate of primary production in the Indian Ocean vis-a-vis the rest of the oceans. Chapter X contains the findings on potential resources of the Indian seas based on estimates from primary production measurements as well as results of exploratory fishery surveys. In fact, resources estimation has been a major objective of these investigations and the results obtained have been most encouraging.

<u>Historical Resumé</u>

Investigations on the production of organic matter in a coastal region were first made in the English Channel. By determining the changes in alkalinity (loss of CO_2) Atkins (1922) estimated the production of dextrose for a unit area. But the values were considered as minimal because the exchange of CO_2 with the atmosphere could not be taken into account. Subsequently Atkins (1923) calculated the annual plankton crop from phosphate consumption and arrived at figures identical with the earlier calculations, the agreement, though fortuitous, lending support to the validity of the alkalimetry method. This was followed by Kreps and Verjbinskaya (1930) who calculated the production in the Barents Sea in terms of 'wet weight' of phytoplankton using Atkins' estimate that the phosphate content of the wet weight of phytoplankton is about 0.15% and arrived at production values in terms of glucose per unit area of surface. In the English Channel again Cooper (1933) calculated the annual phytoplankton production from phosphate consumption which was subsequently corrected to a higher figure on the basis of salt error corrections for phosphate (Cooper, 1938). Seiwell (1935) calculated the annual production of the surface waters in the tropical western north Atlantic based on a previous estimation of oxygen consumption in the vertical water column within the region of investigation. Riley and Gorgy (1948) used the vertical distribution of oxygen in the Sargasso Sea to estimate production. By standard physical oceanographic methods the net oxygen production per day in the depth range between 25m and 100m was estimated which was then converted into its carbon equivalent. Harvey (1950) and Steele (1956) also used phosphate consumption to estimate production at the Plymouth Sea area and Fladen ground respectively. Ryther and Yentsch (1957) have used chlorophyll and light data to compute gross primary production. A review of the various aspects of primary production has been given by Steemann Nielsen (1952, 1958a, 1960, 1963 and 1964), Ryther (1956), Laevastu (1958), Steele (1961) Yentsch (1963) and very comprehensively by Strickland (1960, 1965) and Vollenweider (Ed) (1969).

The first really direct method of estimating the production of organic matter using light and dark bottle was introduced by Pütter (1924) and subsequently by Gaarder and Gran (1927). It had been found from earlier observations that there is often a distinctly demonstrable agreement between the occurrence and extent of the phytoplankton and the changes in the quantity of oxygen in the uppermost layers of water. Because the quantity of oxygen and carbon dioxide of the water are directly influenced by the metabolic processes of the plankton, it is assumed that production can be estimated through their changes. The photosynthesis of the plankton algae and their respiration act in opposite directions. But when photosynthesis predominates, the determinations of oxygen must be expected to give quite good minimum values for the photosynthesis of the plankton algae and thereby for the production of organic substance. This method was subsequently used by Marshall and Orr (1928, 1930) to study the photosynthesis of diatom cultures at different depths in the sea and also to measure the spring plankton production in Loch Striven. Steemann Nielsen (1932, 1937, 1951) also used the technique at various places in the Danish waters. A modification of this method was used by Riley in both eutrophic and oligotrophic regions (1938, 1939, 1941a, 1941b) in extensive plankton investigations of the Tortugas region, western north Atlantic, Long Island Sound and Georges Bank. According to Riley (1938) Atkins' method of measuring phytoplankton production from phosphate consumption used in the English channel is applicable only during the first half of a bloom when the ratio of phosphate regeneration to phosphate consumption is negligibly small. And as there was no possible method for making a natural estimate of production, Riley resorted to the experimental method of suspending light and dark bottles containing plankton. In order to keep conditions as nearly natural as possible the bottles were filled with ordinary sea water and suspended at the same depth from which the samples were taken. The duration of the experiment was five to seven days, for, he found that the oxygen production during shorter periods was not sufficient to counterbalance the normal errors of sampling. Oxygen was determined at the start and end of the experiment. So, it was possible to determine both the oxygen production and oxygen consumption of which the former should be an expression of photosynthesis. However, he believed that the observed values of photosynthesis were smaller than the real and stated that the experiments give only minimal estimates of photosynthesis because of these sources of errors. But later investigations with radioactive carbon and the data on oceanic production collected by the GALATHEA Expedition (Steemann Nielsen, 1952 and 1954) proved that this assumption is not quite correct. The results of Steemann Nielsen's investigations on the production of matter by phytoplankton in oligotrophic tropical areas were very different from those of Riley. The values obtained by the latter were at least 10 times higher. This discrepancy was suggested as the effect of differential growth of bacteria in the light and dark bottles due to the bactericidal effect of sunlight resulting in the over correction for respiration and corresponding over estimation of photosynthesis. But for eutrophic waters with experiments lasting 24 hours the data were comparable. Subsequently Vaccaro and Ryther (1954) showed that there is no difference between the growth or respiration of bacteria in light and dark bottles in experiments lasting for several days. Steemann Nielsen (1954 and 1955a) also demonstrated by laboratory experiments with Chlorella and a marine diatom Thalassiosira that the effect of sunlight may be indirect by producing antibiotics by the plankton algae which increases with light in clear bottles reducing the bacterial activity in them. The difference in oxygen consumption between light and dark bottles was between 12 and 30 times higher than the oxygen production due to photosynthesis of the algae. So, it was presumed that due to the production of antibiotics, plankton algae effect a reduction in the oxygen consumption of the bacteria in the light bottles. According to Ryther (1956) these experiments do not provide any direct demonstration of this phenomenon, whereas those of Vaccaro and Ryther (1954) gave direct contradictory evidence. Ryther (1956) also does not agree with Steemann Nielsen's main objection that production values obtained by long term light and dark bottles measurements are many times higher since values obtained by Ryther by such experiments are too low.

Now the controversy no longer exists as the order of magnitude of global oceanic primary production originally given by Riley (1944) has been reduced by a factor of about 10 (Ryther, 1960 as quoted by Steemann Nielsen, 1964; ~~Valentyne 1965~~; Koblentz-Mishke et al., 1970). The most recent estimate by Koblentz-Mishke et al. (loc.cit.) is 2.5 - 3.0x10^{10} tons (gross production) and 1.5 - 1.8 x 10^{10} tons (net production) of carbon per year, which is almost equal to the values given by Steemann Nielsen and Aabye Jensen (1957). According to Yentsch (MCS), on the whole one can say that the oceans, as compared to the fertile regions of the earth, are virtually deserts. The oceans are productive only because of their size. The total production of the oceans is only 2 - 3 times of that on land, whereas ocean covers 75% of the planet.

In the Indian Ocean, prior to the International Indian Ocean Expedition (IIOE) (1962-65), DANA (1928-30), JOHN MURRAY (1933-34), DISCOVERY (1934) and ALBATROSS (1947-48) expeditions tried to evaluate the productivity from the nutrients and the standing crop of plankton. Gilson (1937) used the nitrate data of JOHN MURRAY expedition to estimate the organic production in the Arabian Sea in wet weight of algae. During the GALATHEA expedition primary production was measured by ^{14}C technique in the western Indian Ocean along the coast of Africa, equatorial part of the Indian Ocean in a section from Mombassa to Ceylon, Bay of Bengal and the Indo-Malayan waters (Steemann Nielsen (1952, 1954; Steemann Nielsen and Aabye Jensen 1957). These studies revealed that, in general, the primary production in the shallow coastal regions of the tropics is high. It was also observed that in the oligotrophic regions, where there was considerable addition of "new" water with high nutrient content into the photosynthetic zone, the daily organic production was high.

During the last decade there has been considerable progress in the study of primary production in the Indian Ocean and the environmental phenomena that regulate it. In connection with the IIOE, between 1959 and 1965 a large number of ships belonging to several countries carried out intensive investigations in the Indian Ocean. The Arabian Sea and under the Australian programme, the 110°E longitudinal section were well studied (Ryther *et. al.*, 1966; Jitts, 1969). After extensive measurements of primary production on board the ANTON BRUUN, Ryther *et al.* (*loc.cit.*) showed that the western Indian Ocean is one of the most productive regions in the world. Some of the highest values ever recorded in the marine environment, excepting those from coral reefs and sea grass beds, were observed in the northern Arabian Sea off the Arabian peninsula. The observations in the western half of the Arabian Sea are summarised by Wooster *et al.* (1967).

A large number of measurements were made on board VITIAZ which have been reported by Kabanova (1961, 1964, 1968). Besides, Burchall (1968) in the Agulhas Current region, Mitchell-Innes (1967) off South Africa and Jitts (1965) in the Australian waters also presented the results of their measurements.

Recently Krey (1973) has given an account of the distribution of chlorophyll and of potential assimilation in the Indian Ocean and Aruga (1973) has reviewed the relation of primary production in the Indian Ocean to chlorophyll and other environmental factors. As part of the U.S.Antarctic Program El-Sayed and Jitts (1973) studied the primary production and standing stock of plankton in the south-eastern Indian Ocean.

Estimates of primary production in the different ecological zones of the Indian Ocean were presented by Moiseev (1969). Prasad, Banerji and Nair (1970) made a quantitative assessment of the primary production in relation to the potential fishery resources of the Indian Ocean and Cushing (1971) for the upwelling regions.

In addition to such direct measurements of primary production reports on phytoplankton pigments of the Indian Ocean by Ichimura and Fukushima (1963), Laird _et al_. (1964) McGill and Lawson (1966), Humphrey (1966) and Humphrey and Kerr (1969) provide a sound basis for the estimation of productivity in the Indian Ocean.

Several studies have been made in the coastal and off-shore regions of the Indian seas. Subrahmanyan (1959) measured the standing crop of phytoplankton by various methods and came to the conclusion that the production on the west coast of India is of a high order comparable to some of the most productive areas in the temperate regions. Prasad and Nair (1960, 1963) made a study of the seasonal variation and magnitude of production in the Gulf of Mannar on the south-east coast of India. The results of investigations carried out at the Central Marine Fisheries Research Institute along the shelf regions of India and the Laccadive Sea, were discussed in relation to the potential living resources by Nair *et al.* (1968) and Nair (1970). Radhakrishna (1969) made a study of the primary productivity in the shelf waters of Alleppey on the south-west coast of India during the post-monsoon period and Shah (1973) presented the seasonal variation of phytoplankton pigments in the Laccadive Sea off Cochin.

The Cochin backwaters have been studied intensively in recent years for plant pigments (Qasim and Reddy, 1967), light penetration (Qasim, Bhattathiri and Abidi, 1968), organic production (Qasim *et al.*, 1969) and nutrient cycle (Sankaranarayanan and Qasim, 1969). Besides the productivity of coral reefs (Nair and Pillai, 1972; Qasim, Bhattathiri and Reddy, 1972) of sea grass bed (Qasim and Bhattathiri, 1971) and liberation of particulate organic matter by coral reefs on an atoll (Qasim and Sankaranarayanan, 1970) have also been investigated.

Thus the Indian Ocean region is no longer the underexplored area it used to be, but is one of the few areas where international co-operation has been marshalled on an unprecedented scale for scientific exploration.

ENVIRONMENT

The area of the Indian seas where regular studies have been conducted lies between 73° and 79° 30' E longitude and upto 10°N on the south-east coast and 15°N on the south-west coast and the Laccadive Sea.

South-east coast - Gulf of Mannar and Palk Bay

This area is exposed to two prevailing monsoons but the rainfall during the south-west monsoon is very little. Extremely turbulent conditions set in during May which continue sometimes even up to August. During this period the drift is from south to north and is particularly strong through the Pamban Pass reaching occasionally a velocity of 5-6 knots. On the contrary at this time Palk Bay is calm. With the onset of the north-east trade winds, generally during September, the Gulf of Mannar becomes comparatively calm. The direction of the drift is reversed and turbulent conditions prevail in Palk Bay. The north-east monsoon then sets in bringing rains and frequent cyclones which originate in the Bay of Bengal.

Seasonal variation of the hydrographic properties:

Fluctuations in the surface temperature of the sea water of Gulf of Mannar show a double oscillation. The minimum is in January which rises steadily till April and after May decreases. There is again an increase sometime during September-October but not to that level of April. The lowering of the surface temperature of the coastal water has been brought about by the strong winds during the south-west monsoon season. The secondary peak is brought by the dying down of the south-west monsoon winds. During the period of observation the lowest temperature recorded in January was 26.1°C and the highest in April was 32°C. The secondary peak of September-October was 30.0-30.5°C. In Palk Bay the surface temperature is of a slightly lower order.

There is a regular seasonal cycle in the salinity in both Gulf of Mannar and Palk Bay. From a low value of 26°/oo in January it gradually increases and remains high ($\geqslant$ 36°/oo) until the middle of November. With the onset of north-east monsoon rains the salinity falls and lowest value is reached in December.

The nutrients at both areas are distinctly lower compared to temperate regions and further they do not show such great fluctuations as are characteristic of temperate waters. The monthly average phosphate values in Gulf of Mannar varied from 0.09 to 0.30 μg.at.P/1, whereas in Palk Bay the range was 0.14 to 0.25 μg.at.P/1.

The fluctuations in the values of nitrates, on the other hand, are greater in Palk Bay, with a range from

1.5 to 5.0 µg.at.N/1. In the Gulf of Mannar monthly average values range from 1.9 to 4.7 µg.at.N/1. The silicate values show wider fluctuations 3.3 to 14.8 µg. at.Si/1 in Gulf of Mannar and 5.3 to 17.9 µg.at.Si/1 in Palk Bay.

The percentage saturation of dissolved oxygen in the surface waters show greater fluctuations and a wider range in Palk Bay. In the earlier investigations Prasad (1954, 1956) found that the quantities of phytoplankton and oxygen saturation did not show any relationship and an apparently overall lower oxygen saturation in Palk Bay which he believed to be due to fewer coral reefs and hence lesser quantity of "imprisoned phytoplankton" or coral zooxanthellae which produced considerable quantity of oxygen during photosynthesis.

The pH values generally vary from 8.4 to 8.7 at both the regions.

The total net plankton (Prasad loc.cit.) in the Gulf of Mannar exhibit well-defined maxima and minima as well as differences from year to year. In general, the cycle is bimodal, with one peak between January and March and another during September-October. In Palk Bay also the distribution is bimodal. However, from January the total plankton steadily increases upto May or June followed by a drop in July-August. Again there is an increase leading to a peak in September-October followed by a decline. The standing crop of plankton is often low during periods of turbulence.

The distribution pattern of total phytoplankton as observed from net collections reveal that in Gulf of Mannar there are three peaks which alternate with periods of low populations. In January the phytoplankton population is high followed by an appreciable decimation in February-March. The concentration increases during April-May and from June to August phytoplankton is low. It once again increases reaching a maximum either in October or in November. Against this abruptly fluctuating phytoplankton cycle in Gulf of Mannar, a more stable distribution is observed in Palk Bay. Starting from a rather low population in January the phytoplankton community increases steadily to a high level by May-June and remains high except for a slight decimation during July-August, upto October, after which there is an appreciable fall. Thus there is only a single prominent peak in Palk Bay in contrast to the three peaks in the Gulf of Mannar. The seasonal variation and succession pattern of the common phytoplankters are discussed separately.

Large quantities of _Trichodesmium_ are noticed particularly in the summer months in Gulf of Mannar but are relatively scarce in the Palk Bay. In both regions Dinophyceae show two maxima with the primary peak in the summer months.

The distribution pattern of zooplankton differs widely at the two areas. When zooplankton is high in Gulf of Mannar it is relatively low in Palk Bay and _vice versa_. Palk Bay is characterised by a richer zooplankton.

South-west coast of India

The west coast of peninsular India forms a narrow belt of low land lying between the sea and the Western Ghats which extend throughout the whole length of the peninsula varying in width from 30 to 150 km inland and running in a direction north-northwest and south-southeast. There are a number of short rivers, many of which drain into the back waters of varying breadth occurring parallel to the coast.

The outstanding feature of the wind system in the Indian seas is a seasonal reversal of the direction associated with the two monsoons. During December to February, the northeast winds of the land origin prevail. The transition begins by about March and lasts through April. By the middle of May the south-west monsoon winds of the oceanic origin are established, which continue to increase gradually until June when there is sudden strengthening. During July and August, the winds blow at their greatest strength and in September, the wind force decreases in preparation for the transition which lasts through October and November. Of the two monsoons, the south-west monsoon endures over a longer period in the Arabian Sea and is stronger and steadier than the north-east one. The onset of south-west monsoon is associated with overcast skies, showers and strong winds, as a result of which the solar insolation is cut off to a large extent. The incident radiation varies from 750 ly on a bright day to 150 ly on a cloudy day in July (Qasim, Bhatta + et al., 1968). Despite the humid conditions evaporation in the Arabian Sea is maximum during the south-west monsoon unlike the usual intense evaporation in winter. (Venketeswaran: 1956; Jagannathan and Ramasastry, 1964).

From the vertical density structure Sharma (M3) has inferred that the process of upwelling of the west coast of India in the deeper layers of about 90 m sets in by March and the upwelled water reaches the surface by May. The cessation of upwelling takes place in August and the reverse process of sinking begins by September. In a period of two months, the vertical movement is 80 m, giving rise to an average intensity of upwelling of 40 m per month - i.e., 1.5×10^{-3} cm sec^{-1} (Sharma, MS). The earlier authors (Banse, 1959; Rama Sastry and Myrland, 1959; Ramamirtham and Jayaraman, 1960) had inferred that upwelling off the south-west coast of India starts with the onset of the south-west monsoon. Regular upwelling is absent north of 15°N.

From July onwards cool water is present below 50 m, some times even at shallower depths which has a low oxygen content 50% or less of saturation appear to be the rule at the inshore regions throughout the entire upwelling season (Banse, 1968).

Seasonal variation of the hydrographic properties of the shelf waters off the west coast of India:

Time-series observations, during research cruises conducted by the Central Marine Fisheries Research Institute since 1957 off the west coast of India on board the Indo Norwegian Project vessels R.V. KALAVA and R.V. VARUNA, have provided data on the hydrology of the west coast. (Banse, 1959; Rama Sastry, 1959; Rama Sastry and Myrland, 1960; Ramamirtham and Jayaraman, 1960; Patil and Ramamirtham, 1963; Ramamirtham and Patil, 1965; Sharma, 1968; Banse, 1968).

The surface temperature all along the coast exhibits a double oscillation during the year with the primary maximum in April and the secondary in November. The corresponding minima take place in July/August and December/January. The low temperatures are spread over a longer period in the north than in the south. The low temperature in the monsoon period is due to reduction in the insolation due to the cloudy conditions and the monsoon rains and run off waters.

Generally, the coastal surface currents off the west coast of India set towards the south from February until late October or November and are reversed during the rest of the year.

There is no prominent seasonal variation in the dissolved oxygen content of the surface waters all along the coast but it does vary considerably in the subsurface layers. However, higher ~~oxygen~~ values of oxygen in the surface waters, in general, are noticed in June and September and lower values in January and July. The stratification of coastal waters during July and August in the depth range of 10 to 30 m results in the depletion of oxygen below the depth of stratification.

The depth of the mixed layer changes from a depth of more than 60 m in January-February to a depth less than 60 m by March-April. By May-June the mixed layer still moves to upper layers and the least depth of less than 20 m is observed in July-August. From then, it starts deepening to a depth of about 40 m by September-October.(Sharma, personal communication).

Studies conducted for prolonged periods at different centres had indicated that phosphate, nitrate and silicate show a seasonal fluctuation, the peaks in their concentration being attained during the south-west monsoon months. It is also found that when there is an abundant supply of these nutrients in the water the ratio of N:P is 15:1, the same as has been found in the temperate regions (Subrahmanyan, 1959).

Banse (1968) after reviewing the hydrography of the Arabian Sea shelf of India had inferred that the seasonal cycle of primary production is apt to be quite similar all along the west coast and that high photosynthetic rates can be expected during the south-west monsoon and later until the cool, deoxygenated subsurface water withdraws from the shelf. During the remainder of the year the density stratification in the surface layer will keep the photosynthetic rates low, near oceanic levels.

MATERIALS AND METHODS

Sea water samples were collected in 'light' and 'dark' bottles at fixed hours in the early mornings from six stations spread over a distance of 30 km in the Gulf of Mannar from July 1957 (Fig.1, stations G1 to G6). Care was taken that no air bubbles were left in the bottles. The bottles were then suspended at the same depth by means of 'cradles' from a platform erected for night fishing at the reference station G1. When the weather was rough, the bottles were attached to a pole, tied to an anchored drum. Samples were taken weekly from the reference station and biweekly from rest of the stations.

In a few trial series, oxygen content was determined at the start and after 24, 48, 72, 96 and 120 hours of the experiment. Production was found to be proportional to the time of exposure until about three days (Fig.2). Hence, experiments lasting 48 hours(for the first year) and 24 hours (for the subsequent years) were conducted. The difference in oxygen concentration between the light and dark bottles was converted into its carbon equivalent using PQ of 1.25 for obtaining gross production values. The difference between the initial and dark bottles was taken as the respiration and that between the light bottle and initial sample

Fig.1 showing the location of stations in the Gulf of Mannar (G1 to G6) and Palk Bay (P1 to P7). G1 is the reference station where most of the observations have been made for a continuous period.

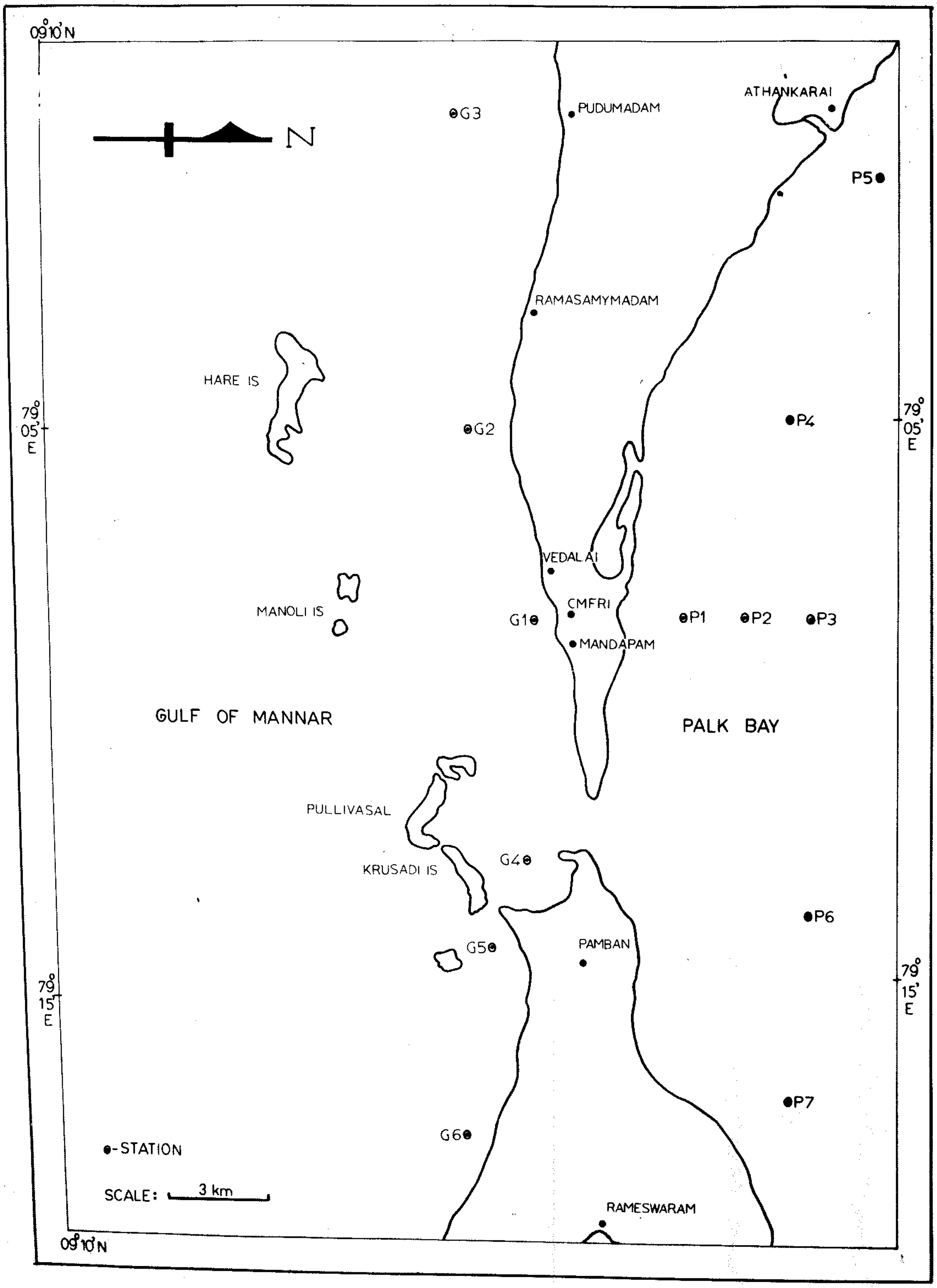
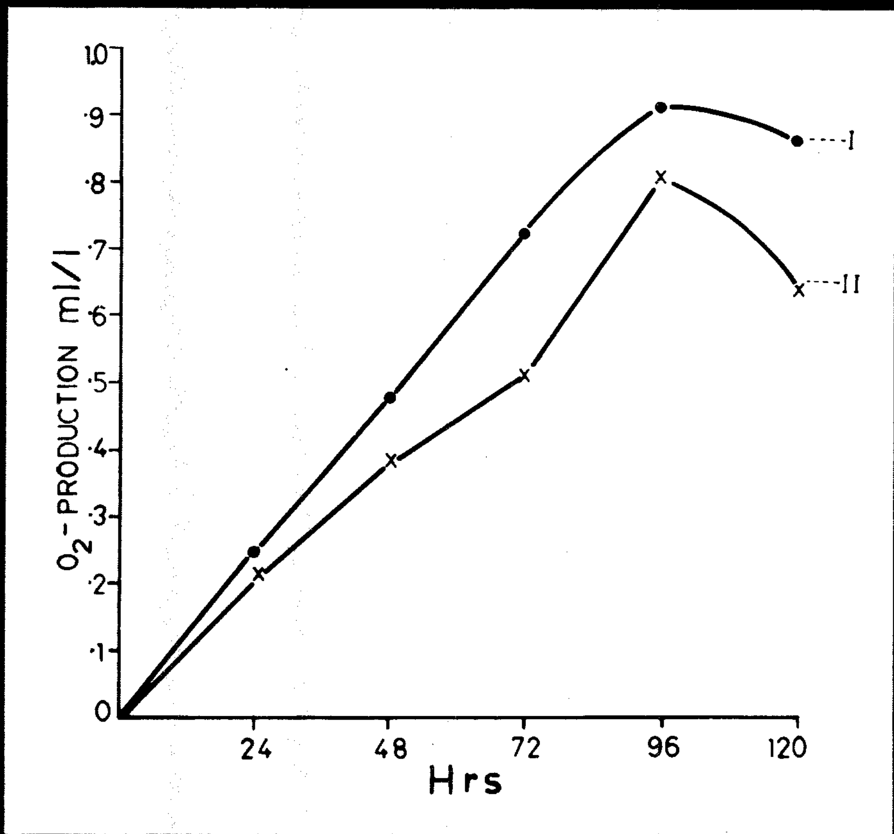

09°10'N
G3
PUDUMADAM
ATHANKARAI
N
P5
RAMASAMYMADAM
HARE IS
79°
05'
E
G2
P4
79°
05'
E
VEDALAI
MANOLI IS
CMFRI
G1
P1
P2
P3
MANDAPAM
GULF OF MANNAR
PALK BAY
PULLIVASAL
KRUSADI IS
G4
P6
G5
PAMBAN
79°
15'
E
79°
15'
E
P7
G6
-STATION
SCALE: 3 km
RAMESWARAM
09°10'N

Fig.2. Gross oxygen production in the light and dark bottle experiments for varying hours of incubation (*in situ*).



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was taken as the 'net community production' (Steemann Nielsen and Hansen, 1959). Analyses were carried out in the Gulf of Mannar till 1962. Salinity, tempterature, pH, pigments, phosphates (total P in filtered and unfiltered samples and dissolved inorganic phosphate so as to determine the different phosphorus fractions including particulate P and organic P), nitrate and silicate were measured by standard methods.

One litre samples were filtered (Whatman and later Millipore filters), and the filter paper treated with 90% acetone and the plant pigments were measured by a Hilger and Watts Spekker Absorptiometer with a red filter (Richards with Thompson, 1952). (Spectronic 20 or a Unicam Spectrophotometer was used after 1964). During the earlier part of the study chromatographically pure chlorophyll a obtained from Sandoz (Switzerland) was used for calibration.

Parallel samples (1 litre) were sedimented, centrifuged and the phytoplankton cells were identified (upto species level wherever possible) and the total counts were taken in both initial and final samples; for this, bigger acid bottles were suspended. From this data growth kinetics of the total phytoplankton population and of the more common species were derived. All the above parameters were measured only in samples taken from the reference station. Only oxyge measurements were made for the rest of the stations.

Total organic nitrogen by the kjeldahl method in the initial and final samples were determined for over an year to examine the suitability of the values of protein obtained by this method as an index of productivity.

From 1965, the Indo-Norwegian Project placed a 28 metre long research vessel, R.V.VARUNA, at the disposal of the Central Marine Fisheries Research Institute for collection of hydrographic data and to conduct exploratory fishing. All the observations on the west coast and in the vicinity of the Laccadive and Maldive Islands and in the equatorial region were made on board this vessel during her research cruises.

^{14}C measurements were made first with ampoules and filters obtained from the International Agency for ^{14}C Determination, Charlottenlund, Denmark. Water samples were collected from the inshore regions of Mandapam (Fig.1) by a glass bottle with a 'snatch mechanism'. Insulated water bottle (Petersen type) with plexi glass inner cylinder (Fig. or a Van Dorn sampler was used for deep water stations. *In situ* experiments were conducted in the shallow regions on the south-east coast from sunrise to noon or from noon to sunset. Most of the measurements on the south-west coast were by simulated *in situ* technique. For this two types of incubators have been used. One was a rotary incubator (Fig.4) somewhat similar to the one used on board the

Fig.3. Insulated water bottles with plexi glass cylinder inside used on board for collection of samples for ^{14}C experiments (open and closed).

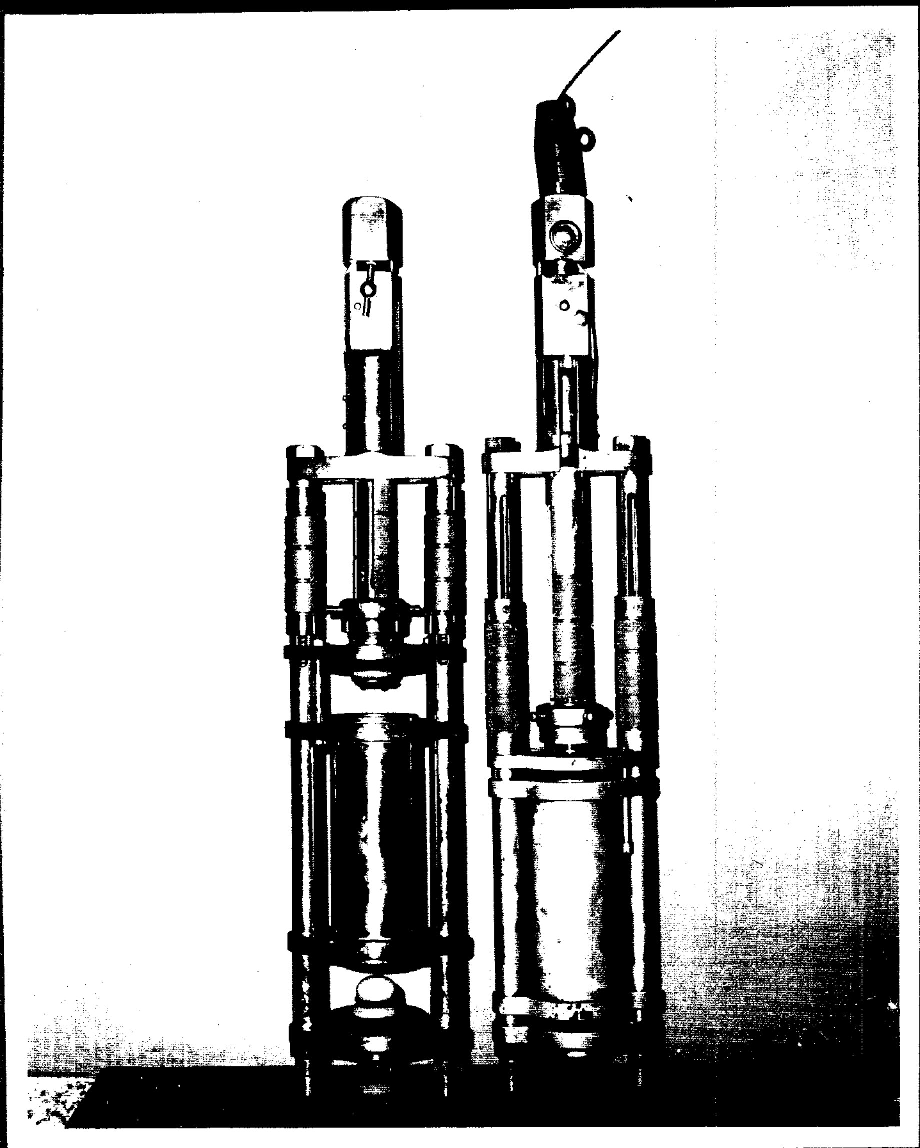

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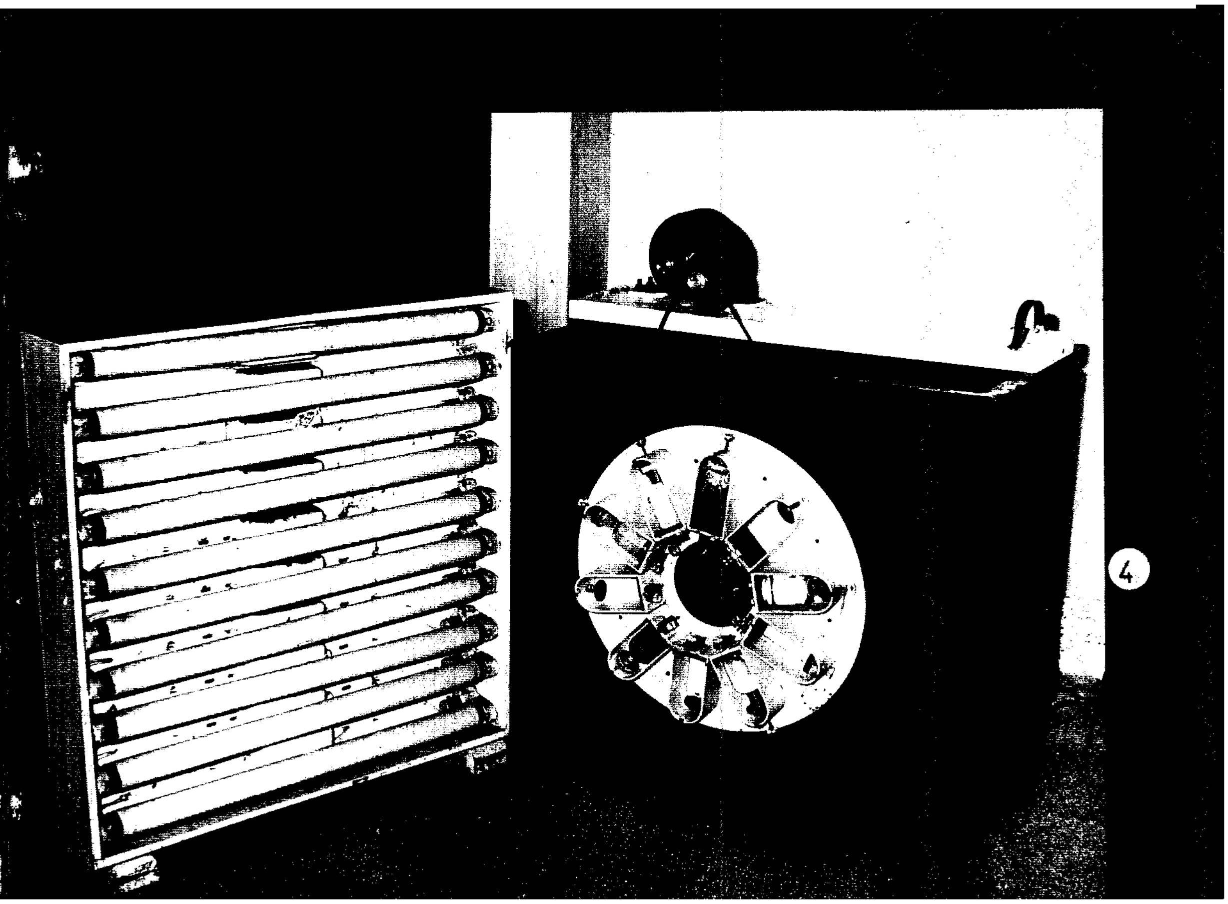
Fig.4. Rotary incubator and light panel for simulated *in situ* experiments. Glass plates with different laye of mesh screen serving as filters can be attached in front of each compartment for the bottles for varying light intensity.

Fig.5. Sun light incubator with bottles. From left 10 60%, 30%, 15%, 1% and dark samples in simulated *in si* technique can be seen.



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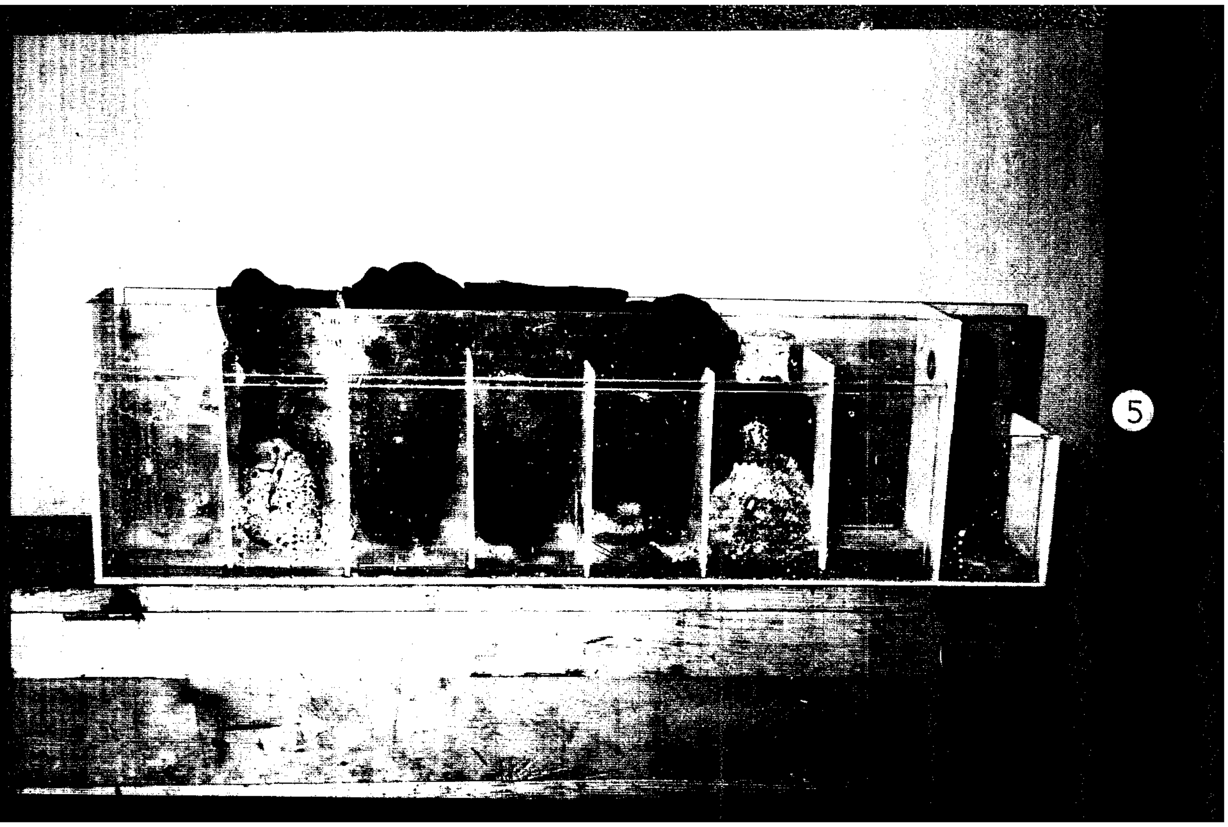

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GALATHEA (Steemann Nielsen and Aabye Jensen, 1957). The rotating disc was fabricated out of pvc and could hold 10 bottles on the front and two on the back (dark bottles). A fluorescent light panel provided a constant light (ca.20 klux).

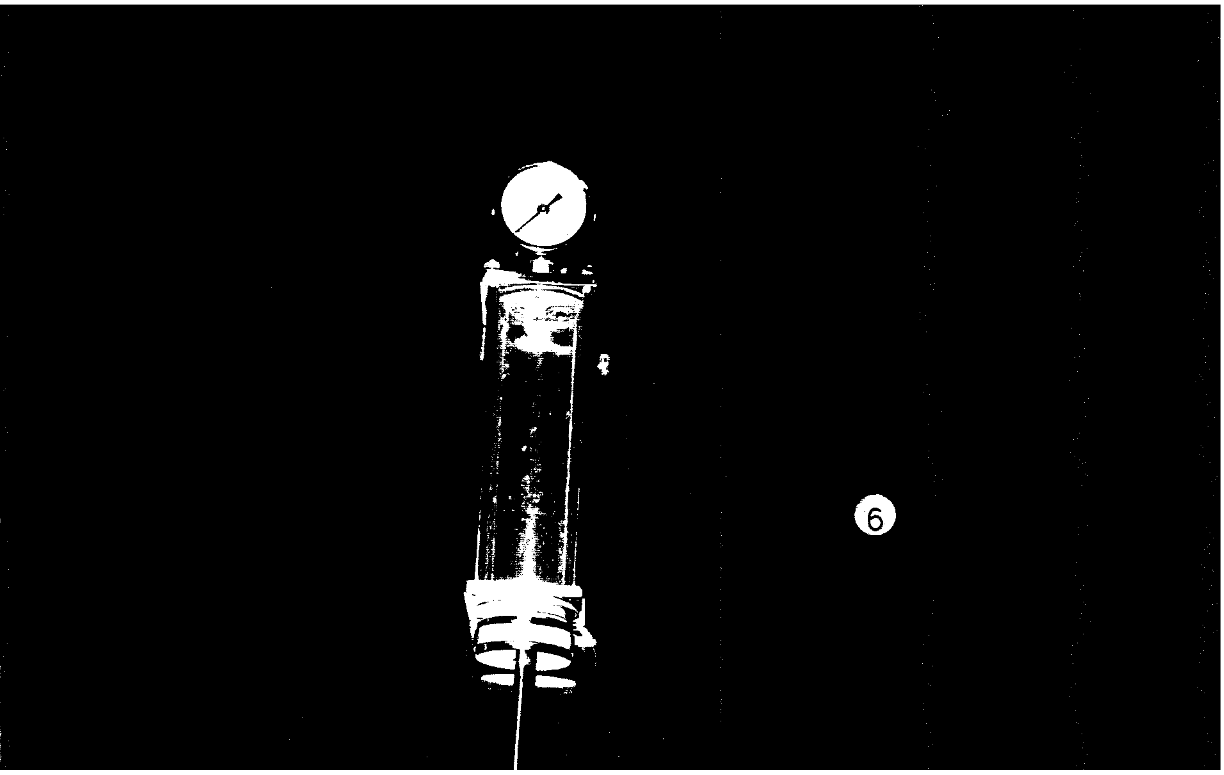
The second one was deck incubator in which sunlight was the source of illumination (Fig.5). Samples collected from the surface and 60%, 30%, 16% and 1% 'light depths' were exposed under mesh-screen neutral density filters transmitting the same percentage of incident radiations. The measurement of light penetration and calibration of neutral density filters were carried out by a Tinsley Irradiance Meter fitted with a blue/green filter (details of measurement given under the section on light penetration).

For incubation under constant light, samples were collected from surface and from depths at which 10% and 1% light intensity were recorded. Temperature correction was made at 5% per degree centigrade as the incubator was circulated with surface water.

Samples were filtered either in a hand-filtration unit (Fig.6) with a cycle pump and in a manifold filtration unit (Fig.7) under suction on board the vessel. Göttingen Membrane filters or Millipore HA filters of approximate 0.5 μ pore size were used respectively for the two

Fig.6. Field filtration unit for 36 mm membrane filters. Filtration by pressure developed with the aid of a bicyle pump.

Fig.7. Manifold filtering unit used on board the research vessel and in the laboratory. Millipore HA filters of 25 mm dia. are fitted on this. Filtration by suction.



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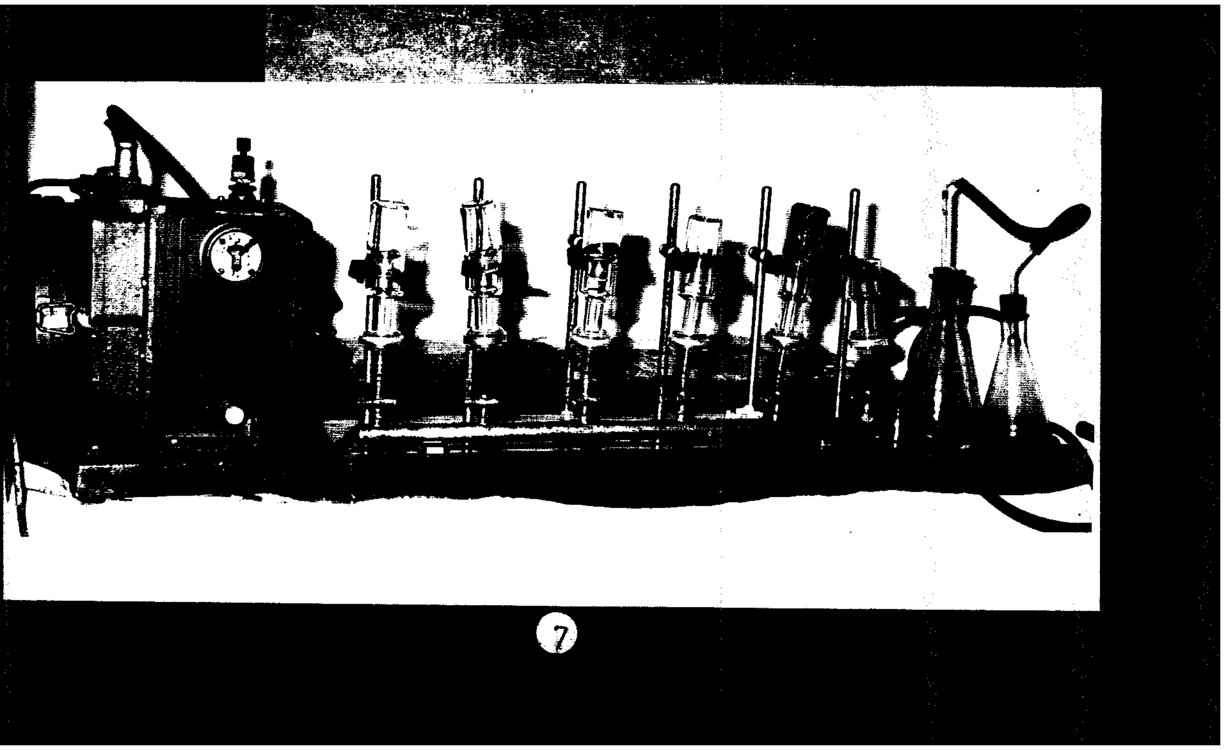

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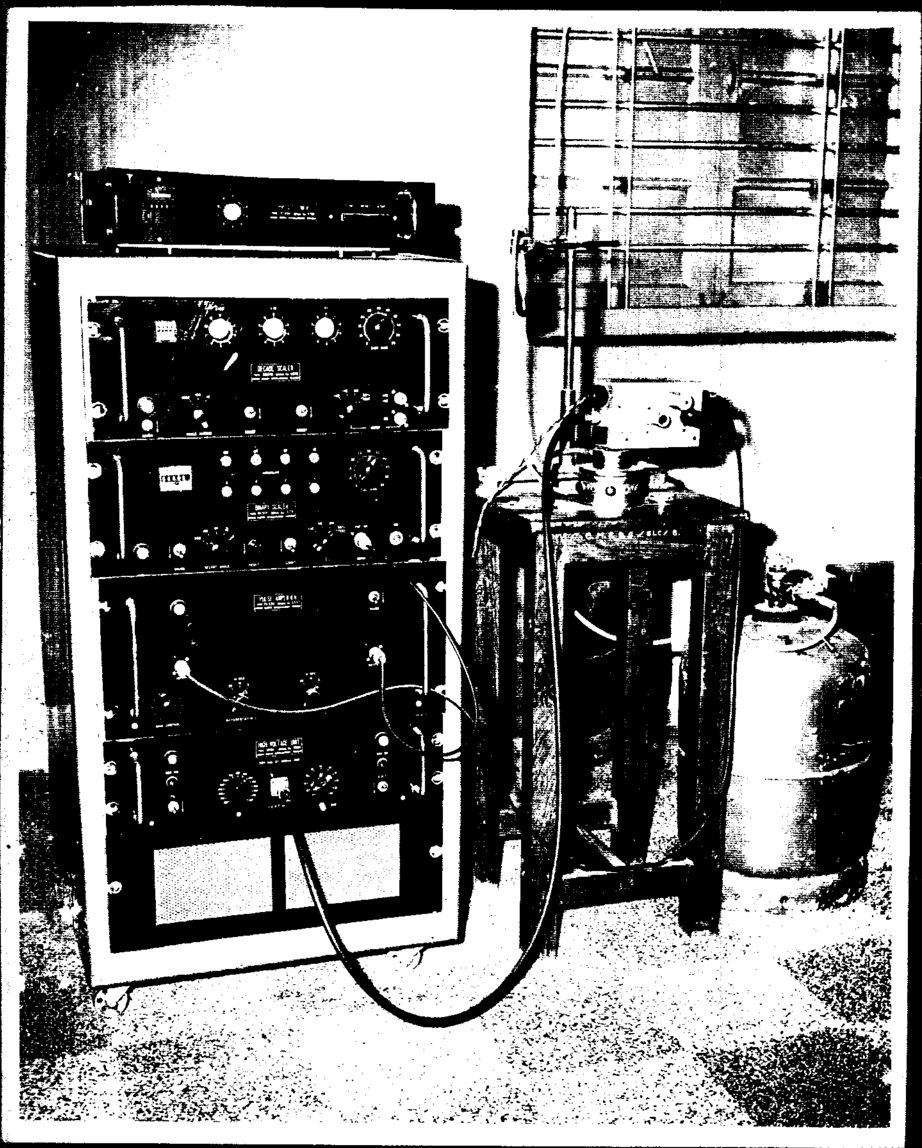


filtering units. Membrane filters were held by plastic holders to prevent buckling while drying. The filters were dried over silica gel and exposed to HCl fumes before counting.

The samples counted at the International Agency have been subsequently corrected by a factor of 1.47 for error in standardization (Steemann Nielsen, personal communication). With the availability of a Gas Flow Proportional Counting System (Fig.8) constructed by the Electronics Division of the Atomic Energy Establishment, Trombay, standardisation and counting were done locally. The methods of standardisation and intercalibration trials carried out are given in the following section.

The production rate per unit volume was calculated by the corrected counts of the filtered sample as a fraction of the added activity and multiplying with the total CO_2 content of the water. In oceanic water it was assumed as 90 mg/1 and for the inshore waters estimated from the tables of Buch (1951) and Harvey (1957). The corrections for isotopic discrimination and interaction of respiration together was put at +10%.

Column production was calculated from in situ and simulated in situ experiments in the deck incubator by integration of the different rates at various depths using the formula of Dyson et al.(1965):

Fig.8. Gas flow proportional counting system. The w less counter with the pre-amplifier in the centre. G used is 'Burshane', cooking gas. The electronic com on the left side consists of a pre-set timer at the two scalers - one decade and the other binary, a pu amplifier and a high voltage unit. The plateau is r broad and the working voltage is 3.8 to 3.9 k.v. The counter gave a zero-thickness counting efficiency of 61.1 ± 2.7%

$$\text{Column production} = \frac{f}{1000}\left\{\left(\frac{a+b}{2}\right)(d_1 - d_0) + \left(\frac{b+c}{2}\right)(d_2 - d_1) + \ldots\ldots\right\},$$

where d_0, d_1, d_2 are the depths sampled;

a, b, c are the respective production rates in gC/m^3/day;

f a factor (1 for *in situ* and simulated *in situ* experiment). In samples incubated under constant light the empirical formula given by Steemann Nielsen and Aabye Jensen (1957) was applied to get the column production. In shallow waters, the values for the best depth (where maximum values are recorded) were multiplied by the actual depth, if it is less than the depth of the euphotic zone and half the product if it is more (Steemann Nielsen and Aabye Jensen, *loc.cit.*). Occasional checks with results of *in situ* experiments were made to assess the magnitude of variability in the different approaches. Column production obtained by simulated *in situ* technique was about 8% higher than the values obtained by *in situ* experiments and 14% than the tank method.

Standardization and intercalibration trials

An essential pre-requisite in the measurements of primary production by ^{14}C technique and the comparison of values obtained by different workers, is the reliable standardization of the ampoules.

When ^{14}C technique was first described by Steemann Nielsen in 1952, he followed the method of Calvin et.al. (1949) for making self-absorption curves. The values of primary production computed from the activity of the ampoule deduced from this method was found to be 31% lower if an end-window counter is used and 10% lower with a window-less counter (Steemann Nielsen, 1965). Hence all the values originally computed by the International Agency have been corrected accordingly.

The ampoules made in India at the Atomic Energy Establishment, Trombay, which were used for all the later measurements were standardised by three different methods, here and also by the original $BaCO_3$ technique at Copenhagen through the courtesy of Prof.E.Steemann Nielsen and Mrs.Ann Marie Bresta of the International Agency for ^{14}C Determination.

By the extrapolation of self-absorption curves

Jitts and Scott (1961).

Planchets of $BaCO_3$ varying from 0.5 to 6.0 mg/cm^2 each containing the same amount of ^{14}C activity were prepared in duplicate from the ampoules of each stock solutions. Each ampoule was diluted to 500 ml with a solution containing 1.36 g of Na_2CO_3 per litre of carbon dioxide-free distilled water. 0.5 ml aliquots of the diluted ^{14}C

solution were pipetted into seven conical flasks treated with "Desikote" and containing 0, 0.5, 1.5, 2.5, 3.5, 4.5 and 5.5 ml respectively of the same Na_2CO_3 solution used in diluting the ampoules. To these flasks 0.05, 0.1, 0.2, 0.3, 0.4, 0.5 and 0.6 ml of 6.26% $BaCl_2$ were then added.

The precipitate of $BaCO_3$ thus formed were allowed to stand for two hours with gentle swirling for every half hour. Planchets were prepared with each of these precipitates by their total transfer (aided by the coating of "Desikote") to Millipore HA filters mounted on the manifold filtering unit. The effective filtering area was 2.5 cm^2. The planchets were sucked dry, dried over silica gel for 24 hours, weighed and counted. The following were the results obtained.

1. Thickness (mg/cm^2)	Logarithm of activity (cpm)	
1.44	3.5603	
2.32	3.4608	
3.12	3.4477	
3.80	3.3870	$Y = -0.0616x + 3.6287$
4.40	3.3432	
5.56	3.3016	

Activity of ampoule by extrapolation = 4.253×10^6 cpm

2. Thickness (mg/cm^2)	Logarithm of activity (cpm)	
0.8	3.6219	
1.0	3.5666	
2.0	3.5344	
3.0	3.4499	
3.8	3.4376	$Y = -0.05574x + 3.6411$
4.9	3.3647	
5.6	3.3369	

Activity of ampoule = **4.376×10^6 cpm**

Liquid scintillation counting method (Jitts and Scott, 1961):

In this the absolute activities (dpm) of the ^{14}C stock solutions were determined by liquid scintillation counting in Australia through the courtesy of Dr.H.R.Jitts and by the candidate at the Atomic Energy Establishment, Trombay.

Indian Stock I - 11.4×10^6 dpm

-do- II - 11.2×10^6 "

International Agency Stock C 82 - 7.45×10^6 "

The zero thickness counting efficiency of the gas flow counter (Fig.3) was determined by counting 19 thin films of ^{14}C labelled plastic mounted on membrane filters. The absolute activities of these filters were determined in the liquid scintillation counting system of CSIRO, Australia. Table1gives the counts and the absolute activities of the filters and the respective counting efficiency.

Table 1. Zero thickness counting efficiency of the gas flow counter

No.	Filter activity (cpm)	Absolute activity (dpm)	Efficiency %
1	656	967	67.8
2	754	1208	62.4
3	738	1194	61.8
4	590	965	61.1
5	718	1240	57.9
6	486	830	58.6
7	780	1273	61.3
8	571	1024	55.8
9	839	1355	61.9
10	728	1150	63.3
11	679	1150	59.0
12	1019	1633	62.4
13	662	1070	61.9
14	768	1248	61.5
15	612	1034	59.2
16	719	1226	58.6
17	720	1115	64.6
18	512	841	60.9
19	639	1062	60.2
		average counting efficiency	61.1 ± 2.7

Hence the activity of the stock solutions obtained by multiplying the absolute activity with the counter efficiency will be as follows:

Indian ampoule stock I - 6.96×10^6 cpm

-do- II - 6.90×10^6 "

International Agency stock C 82 - 4.50×10^6 "

<u>Biological method</u> (Steemann Nielsen, 1965)

Cultures of *Chorella pyrenoidosa* and *C. vulgaris* obtained from the Botany Laboratory, Royal Danish School of Pharmacy, Copenhagen were grown in Osterlind's medium. In a series of experiments with different stock solutions consistent results were obtained.

Table 2. <u>Zero thickness activities of different stock solutions obtained by the Biological method</u>

	Indian stock I	Indian stock II	International of Agency stock
1	6.26×10^6 cpm	7.23×10^6 cpm	--
2	6.33×10^6 "	7.64×10^6 "	--
3	6.19×10^6 "	7.23×10^6 "	--
4	6.50×10^6 "	7.35×10^6 "	--
5	6.33×10^6 "	7.20×10^6 "	--
6	--	7.00×10^6 "	--
Average	6.32×10^6 cpm	7.27×10^6 cpm	4.55×10^6

A very close agreement is observed for the biological method and the liquid scintillation method which lends validity to each other. On the other hand the $BaCO_3$ technique of Jitts and Scott and the original $BaCO_3$ technique gave values, which were 32% each lower and higher respectively. Hence the added activity obtained by the scintillation method was followed for all the calculation due to its comparative simplicity once the counter has been calibrated for its zero thickness counting efficiency.

Intercalibration of stock solutions and counters

Intercalibration of primary production techniques have been conducted by biological oceanographers of several countries, in connection with the International Indian Ocean Expedition, sponsored by SCOR and UNESCO. Reports of such meetings (Doty, 1961 and 1962; Doty et al., 1965) provide a basis for the comparison of values obtained by different national techniques.

After the intercalibration trial at Hawaii in 1961, Dr.R.Raghu Prasad, who represented India gave some ampoules of ^{14}C of C.S.I.R.O., Australia. A series of concurrent in situ experiments were conducted in Palk Bay using the Australian ampoules and International Agency ampoules (Table 3). The results were disconcertingly divergent - C.S.I.R.O. ampoules giving consistently lower values - on the average only (45%).

Table 3. <u>Comparison of values of in situ measurements in Palk Bay using Danish and Australian stock solutions</u>

No.	Period	Station	Depth (m)	Agency stock mgC/m³/hr	C.S.I.R.O. mgC/m³/hr	%
1.	Jun. 62	P1	0	88.46	22.88	29
2.	"	"	5	12.76	4.66	36
3.	Jul.	P2	0	195.16	11.76	6
4.	"	"	4	45.42	20.56	45
5.	"	"	8	4.37	1.73	40
6.	"	"	0	114.60	36.13	32
7.	"	"	4	4.44	1.36	31
8.	"	"	8	3.12	0.99	32
9.	"	P7	0	64.52	13.16	20
10.	"	"	6	12.26	4.86	40
11.	"	"	12	0.74	0.43	57
12.	"	"	0 (Dark)	0.38	0.25	65
13.	"	"	12 (")	0.29	0.23	79
14.	Jul. 62	P5	0	45.26	15.76	35
15.	"	"	4	20.91	7.82	37
16.	"	"	8	3.23	0.81	25
17.	"	"	0 (Dark)	0.50	0.14	28
18.	"	"	8 (")	0.16	0.15	99
19.	Jun. 63	P1	0	10.75	5.05	47
20.	"	"	4	8.67	4.73	55
21.	"	"	8	0.41	0.23	56
22.	"	P3	0	17.20	7.78	45
23.	"	"	4	26.91	11.20	42
24.	"	"	8	12.46	7.08	57
25.	"	"	10	5.20	3.24	62

According to Steemann Nielsen (personal communication) this large difference could be only due to the presence of toxic substances in the Australian stock solutions. It is likely that Cu in ionic form could have been introduced while diluting the original stock as shown by Steemann Nielsen and Wium-Andersen (1970), that when ampoules are made from commercially bought $NaHCO_3$ solutions by dilution with ordinary distilled water (instead of making $C^{14}O_2$ by distillation and using only glass distilled water) they contain ionic Cu which is poisonous for photosynthesis and growth of unicellular algae. Hence, though the Indian ampoules were made strictly according to the original method of Steemann Nielsen (1952) by the Radio-Chemistry Division of the Atomic Energy Establishment, it was thought desirable to make an inter-comparison and assess the magnitude of variability in measurements. Table 4 gives the results of _in situ_ experiments in Palk Bay, using these ampoules along with the Agency ampoules.

Table 4. Comparison of values of primary production obtained by in situ incubation in Palk Bay during September-October, 1964, using Indian and International Agency ampoules standardized by scintillation method and counted in the gas flow proportional counter and the values computed by the Agency after correction for standardisation:

No.	Indian ampoule (5 μc) (Proportional counter)	Agency ampoule (4 μc) (Proportional counter)	Agency ampoule (corrected)
		mgC/m³/hour	
1.	13.55	13.89	14.32
2.	9.54	10.95	11.90
3.	4.69	5.23	4.91
4.	16.15	19.30	22.20
5.	14.16	9.65	12.22
6.	4.06	1.76	1.94
7.	0.13	0.17	0.22
8.	20.33	25.45	31.05
9.	13.88	16.36	19.41
10.	7.74	10.62	7.68
11.	15.05	10.36	12.30
12.	14.18	15.10	14.38
13.	3.40	3.16	3.51
14.	13.70	9.40	8.35
15.	12.90	13.73	9.81
16.	3.09	2.87	2.39
17.	12.10	12.62	9.75
18.	8.66	9.95	8.09
19.	3.70	1.60	1.32
20.	0.12	0.16	0.15
21.	3.11	2.88	1.10
22.	14.32	8.63	9.15
23.	7.74	10.62	9.68
24.	15.05	10.36	12.30
25.	14.18	15.10	14.48
26.	3.4	3.16	3.51

In vitro experiments with natural population did, not only show any reduction in photosynthetic rate but showed a slightly enhanced rate. Thus the primary production measurements have been taken after fully ascertaining the quality of the stock solution and proper standardization.

Samples taken at different times of the day from the same locality and exposed to constant light, so as to study the diurnal variation in the photosynthetic rate gave the following results:-

Samples (hr)	Observed values $mgC/m^3/hour$	Computed by Agency $mgC/m^3/hour$
06	2.49	1.78
08	2.58	1.85
10	4.50	3.20
12	3.50	2.58
14	4.91	4.43
16	3.90	2.72
18	3.48	2.40

The above series of experiments had proved conclusively that the ampoules supplied by the Atomic Energy Establishment, Trombay, and which are used for all the measurements since 1963 have no toxicity which suppresses the rate of photosynthesis. However, when these ampoules were tried with rather dense cultures of *Skeletonema* by

Prof. Steemann Nielsen, he observed a 5% lower rate. This prompted him to suggest that in less dense cultures as well as *in situ* experiments our ampoules might give lesser values, compared to the Danish ampoules.

Comparison of values of primary production measured by oxygen and ^{14}C techniques in different conditions:

In order to have a proper reconciliation of the values of primary production obtained by the oxygen and ^{14}C techniques, it is essential to have direct comparison of values of concurrent experiments. But data on these are very scanty and even the available results are mainly from cultures.

In Table 5A, B and C three sets of results are presented from:

(a) *In situ* experiments in a coastal area at times of high and low production. (Table 5A)

(b) Coral colonies with symbiotic zooxanthellae, (Table 5B)

(c) *In vitro* culture of a green flagellate, *Tetraselmis gracilis* at different stages of growth, (Table 8).

Some authors tend to take values of ^{14}C assimilation as net production (cf. Qasim *et al.*, 1969). This assumption was because the discrepancies between net production obtained from their oxygen experiments were less with ^{14}C than with gross production. Steemann Nielsen (1960, 1963 and 1964) has emphasised that the values obtained by ^{14}C technique is somewhere between gross and net production and for getting either values a correction factor has to be applied. The results in Table 5A clearly indicate that values from ^{14}C method need not necessarily be lower than those from oxygen method. In fact, in the coastal waters when the rate of production is high, values of gross production obtained by the oxygen method has been lower, probably due to the influence of respiration of zooplankters which happen to be in the light bottle.

McAllister et al. (1961) who studied primary production in a coastal area by enclosing the water in a large volume plastic sphere, observed large discrepancies. They consider that in the coastal water ^{14}C method gives low results due to the photosynthetic assimilation of non-labelled carbon. After reviewing the various aspects of the problem, Strickland (1960), while stating that ^{14}C values are nearer to net production than gross, has stressed that it is not established as a universal rule for all marine photosynthesis.

The results obtained suggest that in coastal areas where the rate of production is high, short-term experiments with ^{14}C give values which are nearer to gross production, whereas in waters with low rates, it is nearer to net production. In experiments with flagellates, the values are less than net production due to loss by excretion or at the time of filtration (Table 8). Only in experiments of long duration (24 hours) ^{14}C gives measurements of net production (Steemann Nielsen, 1964). But such duration is normally avoided because of other complications especially in oceanic environment.

Experiments with the corals (Table 5B), though not strictly comparable to those with natural populations of phytoplankton or cultures, give an idea of the relative rates even under very special conditions. Each specimen taken alive from a nearby reef was acclimatised to the aquarium conditions (details given in appendix 3 (Pillai and Nair, 1972) and was subjected to two sets of experiments. (1) Determination of gross production by changes of oxygen in light and dark jars; (2) Determination of the ^{14}C uptake by the symbiotic zooxanthellae alone. Since the gross production is a function of the respiration of the entire coral colony, whereas ^{14}C uptake represents only the contribution by the zooxanthellae, the usual correction for respiration is inadequate in this case. Hence the respiration of the entire colony obtained from dark bottle correction has been added to ^{14}C values to get the 'adjusted gross production' by the latter method. The contribution of boring ge which has not been determined and which is sometimes ry significant, loss of zooxanthellae during separation, hibition of photosynthesis from too much light (as zoonthellae are normally conditioned to the milder intenity while inside the corals), loss of photosynthetic oducts by cell lysis are some of the factors that could ndividually or collectively affect the results. Hence a al comparison is untenable. However, in about 50% of the ases the results are fairly comparable. Only in two cases he ^{14}C values are higher, whereas in most of the experiments hey were lower. Percentage realised by ^{14}C against net roduction measured by light bottle ranged between 40-80%. n *Goniastrea pectinata* and *Goniopora stokesi* ^{14}C uptake as more than the net production measured by oxygen chnique (130 and 103% respectively) (Pillai and Nair, 972, Table V).

Oxygen and ^{14}C technique do not always yield conrdant results as photosynthesis consists of a complex f reactions which do not have fixed relationships with each ther and the two methods measure the rate of different actions; besides fixation of ^{14}C by carboxylation reactions and release of extra cellular products of photoynthesis bring in a certain amount of disparity (Fogg, 963 and 1969).

Table 5. Comparative values of primary production by oxygen and ^{14}C technique.

(A) In situ experiments:

No.	Station	Depth	^{14}C mgC/m^3/day	O_2 (PQ=1)	O_2 (PQ=1.25)	Ratio O_2 / ^{14}C PQ=1	Ratio O_2 / ^{14}C PQ=1.25
1.	G1	0	390	393	316	1.01	0.81
2.	"	5	188	163	131	0.87	0.70
3.	P1	0	37	63	50	1.70	1.35
4.	"	4	41	32	26	0.78	0.63
5.	"	8	53	210	169	3.96	3.19
6.	Laccadives	0	13	93	74	7.15	5.69
7.	"	0	8	135	108	16.87	13.50
8.	"	0	56	135	108	2.41	1.93
9.	P1	0	639	564	452	0.88	0.71
10.	"	8	143	81	65	0.57	0.45

(B) Experiments with live corals:

No.	Species	Gross production mgC	Respiration mgC	^{14}C values adjusted to gross (mgC)	Ratio $O_2/^{14}C$
1.	*Acropora corymbosa*	2.93	1.29	2.58	1.16
2.	*A. erythraea*	2.66	0.97	1.95	1.36
3.	*Cyphastrea microphalma*	1.13	0.47	1.04	1.09
4.	*Favia pallida*	1.51	0.56	0.95	1.59
5.	*Favites abdiata*	0.66	0.23	0.51	1.29
6.	*Goniastrea pectinata*	0.55	0.28	0.63	0.87
7.	*Goniopora stokesi*	3.16	1.0	3.28	0.98
8.	*Pocillopora damicornis*	3.94	1.31	3.39	1.16
9.	*Porites solida*	1.05	0.29	0.49	2.14

THE PHYTOPLANKTON OF THE INSHORE WATERS OF MANDAPAM

Qualitative and quantitative studies on the phytoplankton of the inshore waters of Mandapam were based on centrifuged water samples and net collections. Sixty species commonly occurring in the plankton were classified into bio-geographical groups and the general character of the diatom flora of the Gulf of Mannar and Palk Bay were described by Prasad and Nair (1960). It was found that the biological spring falls in May or some time by the end of April and the secondary maximum occurs in October or November.

Fifteen species are well-represented in the collections and most of these are forms with a summer maximum but remain more or less important throughout the season while a few are with a distinct 'spring' and 'autumn' maxima. It is also found that Palk Bay is having a larger breeding stock of autochthonous diatoms which are mostly neritic, whereas in the Gulf of Mannar there are more littoral and oceanic forms.

Most of the species occurring both in the Gulf of Mannar and Palk Bay and constituting the bulk of net collections are *Chaetoceros* spp., *Rhizosolenia alata*, *R. imbricata*, *Thalassionema nitzschioides*, *Thalassiothrix frauenfeldii*, *Bacteriastrum hyalinum*, *Biddulphia sinensis*.

Species such as Thalassiosira coromandeliana, Guinardia flaccida, R.styliformis, R.calcar-avis, R.castracanei, Hemiaulus sinensis, Bacteriastrum varians, Chaetoceros denticulatum, Climacosphaenia elongata and Asterionella japonica are also found in good numbers especially in Palk Bay. Tropical oceanic forms such as Chaetoceros coarctatus, with Vorticella, Ditylum brightwelli, Biddulphia sinensis and Hemidiscus hardmannianus are found very commonly in the Gulf of Mannar. Prasad (1954) observed blooms of single species of Rhizosolenia, R.imbricata in February and R.alata in March during two succeeding years in the Gulf of Mannar, whereas during the summer as well as in August-September maxima more than one genus and several species were noticed flowering. He also observed that there are variations in the species composition of the diatom maxima taking place at different months of the year.

Seasonal and quantitative variation of the common phytoplankters of Mandapam:

Of the sixty two species of diatoms recorded from this area, fifteen species are well-represented in the net collections. Most of these are forms with a summer maximum but remain more or less important throughout the season while a few are with a distinct 'spring' and 'autumn' maxima. Seasonal occurrence of the more common species are discussed below:

Asterionella japonica has a sparse occurrence in the Gulf of Mannar except during the summer. In Palk Bay it forms an important constituent in the plankton from February to April and from June to November with the maximum in August when it appears in blooms. There seems to be a regularity in their occurrence in Palk Bay during consequtive years whereas it is not the case in the Gulf of Mannar. In temperate waters it is considered as one of those erratic organisms with extremes of abundance which are not seasonal (or even annual) in occurrence but are based on more or less fortuitously favourable combinations of the required conditions (Allen 1945).

Bacteriastrum hyalinum occurs in both the areas during summer blooms and also during the latter part of the year. *B. varians* is a more warm water species that forms one of the constituents of the phytoplankton bulk of April-May and sometimes in August. In net collections it appears in swarms in both the areas from May to June. The genus *Bacteriastrum* can be considered as one of the four dominant genera that makes up the diatom bulk of this area.

Biddulphia sinensis is considered as a tropical neritic species which has invaded the temperate waters where it has become a permanent member of the plankton. It has also been used as an indicator of currents and for determination of the rate of flow of currents (Lebour 1930). Being a tropical species it is more common than B.mobiliensis. In the Gulf of Mannar it occurs almost throughout the year with the maximum during summer.

Chaetoceros indicus was described for the first time from the plankton of the Madras coast (Subrahmanyan 1946). It is abundant in net collections in both the areas and forms one of major constituents of the diatom maxima. It is comparatively more abundant in Palk Bay. In the Gulf of Mannar it occurs in small numbers intermittently from April to December.

Chaetoceros lascinosus is a prominent species in Palk Bay occurring regularly during both peaks and is almost totally absent at other times of the year. In the Gulf of Mannar it occurs intermittently during May to December.

Chaetoceros lorensianus occurs in the Gulf of Mannar almost throughout the year and form a major part of the diatom population and appears in large number during the diatom blooms. C.lorensianus together with C.lascinosus form the bulk of Chaetoceros abundance. C.lorensianus occupies the place of C.debilis in temperate waters being the most abundant form of Chaetoceros when taken on a round-the-year basis though occasionally stray blooms of C.lascinosus may occur.

Chaetoceros peruvianus occurs commonly in the Gulf of Mannar from April to December at intervals. In November it occurs persistently with a regular succession. In Palk Bay it is present in fairly good numbers from May to November.

Coscinodiscus gigas occurs in both places almost throughout the year in few numbers. In June it occurs more commonly in the Gulf of Mannar.

Hemidiscus hardmannianus has a greater abundance in the Gulf of Mannar than in Palk Bay. It occurs throughout the year at intervals, and is very common in the plankton with maximum abundance in March-April in the Gulf of Mannar.

Rhizosolenia alata is a temperate oceanic species which occurs in both the areas exhibiting wide fluctuations.

Rhizosolenia imbricata occurs in the Gulf of Mannar at intervals. It is commonly found in the net collections in February, March and in November. In Palk Bay it forms a dominant member of the genus from June to September.

Thalassionema nitzschioides occurs almost throughout the year in the Gulf of Mannar with occasional absence. But in Palk Bay it appears only during the two major blooms. Though a neritic form it is circum-global and its distribution pattern supports the contention of some investigators that neritic species can survive in oceanic environments well, if they are transported there (Smayda,1958).

Thalassiothrix frauenfeldii is considered as the most important species occurring in the plankton of both the areas. In the Gulf of Mannar it occurs almost throughout the year, and is a dominant member of the summer blooms. The maximum occurrence is in April/May but in October also it occurs in good numbers. *T.frauenfeldii* is considered an oceanic temperate species preferring warmer waters.

Littoral forms such as *Pleurosigma* spp.and *Navicula* spp. are more abundant during or immediately after the period of turbulence.

Palk Bay is more or less an enclosed area and there is a relatively more regular seasonal succession of species which is probably an indication of a larger autochthonous breeding stock of diatoms. On the other hand Gulf of Mannar has conspicuously more oceanic species which supports the observations of Prasad (1954) about the possible incursion of oceanic surface waters in the coastal area during June-August as evidenced by high salinity and low silicate and also the presence of open ocean planktonic animals. The relative abundance of phytoplankters at station G1 is given in Table 6.

Table 6. Seasonal variation and relative abundance of the phytoplankters in Gulf of Mannar

BACILLARIOPHYCEAE CENTRALES	J	F	M	A	M	J	J	A	S	O	N	D
1. *Melosira sulcata*	R	F	R	R	C	R	-	R	-	-	F	R
2. *Hyalodiscus subtilis*	-	-	-	-	-	-	R	R	F	-	-	-
3. *Stephanopyxis palmeriana*	C	F	R	-	-	-	-	-	-	-	-	-
4. *Skeletonema costatum*	-	-	-	-	-	-	-	R	C	R	-	-
5. *Thalassiosira subtilis*	C	R	-	-	-	-	-	-	-	-	F	R
6. *Coscinodiscus* spp.	F	C	C	F	-	R	C	F	R	-	F	F
7. *Corethron hystrix*	-	-	-	-	-	-	-	-	C	F	-	R
8. *Lauderia annulata*	F	-	-	-	-	F	-	-	-	F	R	R
9. *Schroederella delicatula*	-	-	-	-	-	-	-	F	R	-	F	R
10. *Leptocylindrus danicus*	-	-	-	-	-	-	-	R	F	-	C	A
11. *L. minimus*	F	F	F	-	-	-	-	-	-	R	C	A
12. *Guinardia flaccida*	F	R	-	-	-	-	-	-	-	F	-	-
13. *Rhizosolenia Stolterfothii*	F	-	F	-	-	-	-	R	R	F	R	F
14. *R. robusta*	-	-	-	-	-	-	F	F	-	-	-	-
15. *R. imbricata*	F	-	F	-	-	-	-	-	R	F	R	-
16. *R. styliformis*	F	-	F	-	-	-	-	R	R	F	C	R
17. *R. setigera*	-	-	-	-	-	-	-	R	R	-	R	R
18. *R. alata*	F	R	A	-	-	-	-	-	-	F	F	R
19. *R. calcar-avis*	F	-	-	-	-	-	-	-	R	-	F	-
20. *Bacteriastrum hyalinum*	C	-	F	A	-	-	-	R	R	F	R	F

	J	F	M	A	M	J	J	A	S	O	N	D
21. *Chaetoceros coarctatus*	-	-	-	-	-	-	-	F	F	-	-	-
22. *C. peruvianus*	F	-	-	-	-	-	-	-	R	F	R	-
23. *C. lorenzianus*	-	-	-	-	-	-	-	R	-	-	F	-
24. *C. diversus*	R	-	F	-	-	-	R	-	-	-	F	R
25. *C. laevis*	-	-	-	-	-	-	-	-	-	F	-	R
26. *C. indicus*	-	-	-	-	C	A	C	C	F	-	F	-
27. *C.* spp.	R	R	A	B	-	-	-	-	-	B	C	-
28. *Streptotheca* sp.	-	-	-	-	-	-	-	-	-	-	R	R
29. *Bellerochea malleus*	R	-	-	-	-	-	R	-	-	F	-	R
30. *Ditylum brightwelli*	R	-	-	-	-	R	F	-	-	-	R	R
31. *Triceratium favus*	-	-	R	-	-	-	-	R	-	-	R	R
32. *Biddulphia sinensis*	R	R	R	R	C	A	A	F	R	-	R	R
33. *B. mobiliensis*	R	-	R	F	R	R	-	-	-	-	R	R
34. *Hemiaulus hauckii*	R	-	-	-	-	-	-	-	-	R	R	R
35. *Hemidiscus herdmannianus*	C	R	R	R	-	-	R	-	-	-	R	R
PENNALES												
36. *Rhabdonema mirificum*	R	F	R	F	F	R	-	C	R	R	-	R
37. *Grammatophora marina*	-	F	R	-	-	R	-	-	-	-	-	F
38. *Licmophora abbreviata*	-	R	F	-	-	-	-	-	C	-	R	-
39. *Climacosphenia moniligera*	R	R	F	R	-	-	C	R	F	F	R	R
40. *Fragilaria oceanica*	-	-	-	-	-	-	-	-	-	F	-	-

	J	F	M	A	M	J	J	A	S	O	N	D
41. *Synedra* spp.	-	R	-	-	-	-	-	-	-	F	R	-
42. *Thalassionema nitzschioides*	F	R	F	R	C	R	F	-	R	R	C	F
43. *Thalassiothrix frauenfeldii*	R	F	F	C	C	R	-	-	R	F	F	R
44. *Asterionella japonica*	R	C	C	F	-	C	R	A	R	R	R	R
45. *Cocconeis* spp.	R	R	F	R	R	R	F	R	R	R	F	R
46. *Achnanthes* spp.	-	-	-	-	-	-	-	-	R	F	R	-
47. *Gyrosigma balticum*	-	R	-	-	-	-	-	R	-	R	F	-
48. *Pleurosigma normanii*	C	C	C	B	C	R	-	R	F	R	R	F
49. *Diploneis weissflogii*	R	R	-	-	-	-	R	R	R	-	R	R
50. *Navicula* spp.	F	F	C	F	R	C	R	-	R	C	R	F
51. *Pinnularia* spp.	-	-	-	-	-	-	-	R	R	-	-	-
52. *Amphiprora gigantea* var. *sulcata*	-	-	-	-	-	-	-	-	-	-	R	R
53. *Amphora* sp.	R	R	-	-	-	R	F	R	-	-	-	R
54. *Eunotia* sp.	-	-	-	-	-	-	-	-	-	-	R	R
55. *Cymbella* sp.	R	F	R	F	R	R	-	F	R	-	R	R
56. *Bacillaria paradoxa*	-	F	-	-	-	-	-	R	R	-	-	R
57. *Nitzschia closterium*	R	C	C	F	-	-	R	F	-	F	R	R
58. *N. sigma*	R	R	R	-	-	-	-	-	-	-	R	R
59. *N. longissima*	-	-	-	-	-	-	-	-	-	F	-	R
60. *N. seriata*	F	-	F	-	-	-	-	R	R	-	R	F
61. *N.* spp.	-	A	C	-	-	R	F	F	R	R	R	R
62. *Surirella* spp.	-	R	-	-	-	-	-	-	R	-	R	R

DINOPHYCEAE	J	F	M	A	M	J	J	A	S	O	N	D
63. *Ceratium* spp.	R	-	-	-	-	-	-	R	C	F	R	F
64. *Peridinium* spp.	-	-	-	-	-	-	-	F	R	R	R	R

- -

B = Bloom (more than 1,00000 cells)

A = Abundant (more than 10,000 cells)

C = Common (more than 1,000 cells)

F = Few (more than 500 cells)

R = Rare (less than 500 cells)

- = Absent

General growth kinetics of the total population and of the more common species of diatoms:

The mean generation time and growth constant have been studied elsewhere for a number of phytoplankters especially diatoms grown in cultures. But very little work has been done with marine phytoplankters in the natural environment. In fact, no results have been reported from the Indian seas.

The phytoplankters increase in numbers by cell division. The individual cells have a variable generation time when they double themselves. This changes according to the environmental conditions and the mean value for a division time is expressed by the equation:

$$\ln.n_t = \ln.n_o + kt$$

where n_o is the initial number of cells, n_t is the number of cells at the end of time $\underline{t}$ expressed in hours and $\underline{k}$ a constant that depends on the organism and the environment. If t_g is the mean generation time for a cell in hours,

$$t_g = \frac{0.7}{k} \quad \text{or } k = \frac{0.7}{t_g} \text{ (Strickland, 1960).}$$

So by taking the natural logarithm (ln) of cell numbers at the initial and final phase of the experiment the growth constant ($\underline{k}$) and mean generation time ($\underline{tg}$) can be calculated.

According to Strickland (1960) $\underline{k}$ values for marine phytoplankters (mainly diatoms) are generally near the optimum and the results are rarely outside the range of 0.02 to 0.15 $(\text{hours})^{-1}$. For example Braarud (1944) reported about 0.15 for small diatoms decreasing to 0.07 to 0.05 for larger species. The values given by Smayda (1957) are near to 0.05 and Harvey (1934) suggested a value of 0.12 for _Chaetoceros_. For _Phaeodactylum tricornutum_ _k_ is approximately 0.06 (Ketchum 1939 as Raymont and Adams, 1958). The generation time for _Gymnodinium_ is 12 hours indicating a _k_ around 0.06 (Ragotskie and Pomeroy, 1957). The t_g value for culture of _Gonyaulax polyedra_ is nearly 2 days (Sweeny and Hastings, 1958). McLeod (1957) gives t_g as 12 hours for _Dunaliella euchlora_. For total phytoplankton population Harvey, _et al._ (1935) estimated _k_ as about 0.035.

Table 7A to C give the _k_ and t_g values for mixed populations of phytoplankton and a few common species of diatoms in the Gulf of Mannar, enclosed in light and dark bottles, along with experiments for measuring primary production. In both there was increase in numbers; but in the dark bottles as there was no addition of new material by photosynthesis (because of the continuous darkness) _k_ values tend to be lower. But the populations exposed to the diurnal variations of light in the clear bottles would represent almost those in natural conditions.

The shortest generation time recorded was 5 hours for _Thalassionema nitschioides_ representing a _k_ value of 0.13. For the mixed population the shortest doubling time was 9 hours (_k_ = 0.08). For _Pleurosigma_ and _Navicula_, the common littoral forms occurring in the samples, the doubling time on the average is a little less than 24 hours - Table F and G. Lanskaya (1961) reported a three-hour doubling time (k = 0.23) is possible for Skeletonema and the time of division as early morning hours. It is likely that some of the k values given in the table would have been higher if the grazing effect had been eliminated by filtering off the zooplankters before incubation.

In coastal areas the nature of phytoplankton production is one of large blooms followed by periods of grazing and decay. The rate of increased productivity arises mainly from an increase of the standing crop and not of the growth constant k since k does not follow a seasonal pattern.

Table 7a. Growth kinetics of mixed population of phytoplankton and some selected species in light and dark bottles during a 48-hour period of incubation (in situ)

Month	n_o	Light bottle n_t	k	t_g	dark bottle n_t	k	t_g
Jan.	8,770	85,400	0.047	15	15,400	0.017	41
	24,870	107,870	0.031	23	50,640	0.015	47
	14,610	54,890	0.028	25	23,120	0.010	70
	33,420	85,110	0.019	37	131,190	0.018	25
	51,180	119,190	0.018	39	--	--	--

(Contd. Table 7a)

1	2	3	4	5	6	7	8
Feb.	8,320	12,210	0.008	88	20,290	0.019	37
	15,360	22,460	0.008	88	13,220	-	-
	7,610	23,480	0.023	30	6,410	-	-
	15,210	92,000	0.038	18	19,040	0.013	54
Mar.	19,870	47,710	0.018	39	16,640	-	-
	6,200	51,170	0.044	16	6,020	-	-
	21,090	221,200	0.049	14	75,600	0.026	27
	115,090	163,510	0.073	10	14,460	-	-
Apr.	27,710	57,600	0.015	47	13,100	-	-
	1510,000	5020,000	0.025	28	2016,000	0.006	117
	159,000	476,000	0.023	31	160,000	-	-
	1142,000	22024,000	0.062	11	112,000	-	-
May	76,200	744,000	0.048	15	119,400	0.009	78
	62,800	203,200	0.024	29	22,600	-	-
	22,200	48,800	0.016	43	26,200	0.003	233
	30,400	216,000	0.041	17	92,000	0.023	30
	10,400	19,000	0.013	54	9,600	-	-
Jun.	2,200	7,800	0.026	27	6,400	0.022	32
	3,000	3,600	0.004	175	4,400	0.008	88
	410	770	0.013	54	—	—	—
Jul.	640	2,050	0.024	29	1,450	0.017	41
	1,870	31,800	0.059	12	4,160	0.017	41
	280	2,104	0.042	17	650	0.018	39
Aug.	100	1,330	0.054	13	910	0.046	15
	670	1,520	0.017	41	540	-	-
	510	1,790	0.026	27	1,130	0.017	41

(Contd. Table 7a)

1	2	3	4	5	6	7	8
Sep.	350	690	0.014	50	950	0.021	33
	1,280	14,490	0.051	14	6,320	0.033	21
	4,190	12,310	0.023	31	1,100	-	-
Oct.	150	1,840	0.052	13	2,300	0.057	12
	6,600	323,950	0.081	9	107,700	0.058	12
	3,380	5,060	0.008	8	1,530	-	-
	150	1,840	0.052	13	2,300	0.057	12
Nov.	61,480	237,560	0.028	25	33,640	-	-
	34,540	253,600	0.042	17	40,000	-	-
	12,730	151,660	0.052	13	61,510	0.033	21
Dec.	22,940	123,730	0.035	20	34,640	0.009	78
	16,980	98,210	0.037	19	33,040	0.014	50
	24,030	51,980	0.016	44	24,570	-	-
	20,630	48,180	0.018	39	14,360	-	-

7b. <u>Coscinodiscus</u> spp.

Month	n_o	n_t	k	t_g
July	72	155	0.016	44
	6	37	0.038	18
Aug.	10	30	0.023	30
Sept.	20	100	0.034	21
Nov	640	3,040	0.032	22
	1,600	4,500	0.022	32
Dec.	6,000	37,600	0.038	18
	4,000	13,000	0.020	35
	1,400	7,400	0.035	20
	1,600	4,800	0.023	30
Jan	200	1,600	0.043	16
	200	1,800	0.046	15
	400	1,400	0.026	27
	200	400	0.014	50

7c. Chaetoceros spp.

	n_o	n_t	k	t_g
Apr.	12,200	20,800	0.011	64
	1,480,000	5,000,000	0.025	28
	1,100,000	22,000,000	0.062	11
	70,000	700,000	0.048	15
May	51,000	1,900,000	0.075	9
Dec.	1,630	3,800	0.018	39
Jan.	5,200	20,000	0.028	25
Oct.	4,300	320,000	0.087	8
Nov.	560	1,420	0.019	37
	7,520	62,000	0.044	16
	3,200	22,400	0.041	17

7d. Thalassionema nitzschioides

	N_o	n_t	k	t_g
July	12	123	0.048	15
Sept.	30	350	0.051	14
Nov.	9,920	76,260	0.042	17
	4,000	90,000	0.065	11
	25,000	45,000	0.012	52
Dec.	900	4,960	0.036	19
	4,000	8,600	0.016	44
	40	25,400	0.134	5
Apr.	60	9,400	0.105	7
May	11,200	38,000	0.025	28
	13,000	100,000	0.043	16
	4,200	11,000	0.020	35
Jun.	400	4,200	0.049	14
	120	260	0.016	44

7e. Thallassiothrix frauenfeldii

	n_o	n_t	k	t_g
Oct.	70	350	0.022	32
Nov.	2,000	2,600	0.005	140
	2,000	20,000	0.048	15
	9,600	13,120	0.006	117
	900	4,960	0.036	19
Dec.	800	4,000	0.034	21
	110	4,000	0.075	9
	2,200	4,000	0.012	58
	40	2,300	0.089	8
	800	5,200	0.039	18
	30	800	0.068	10
May	2,000	5,000	0.019	37
	6,200	16,000	0.020	35
	1,600	2,600	0.010	70

7f. Pleurosigma spp.

	n_o	n_t	k	t_g	k	t_g
Jan.	2,000	22,000	0.051	14		
	5,400	33,200	0.038	18		
	10,000	60,000	0.037	19		
	10,200	75,400	0.042	17	0.042	17
Feb.	3,400	15,200	0.031	22		
	4,200	13,600	0.025	28		
	6,200	34,600	0.028	25	0.028	25

(Contd. Table 7f)

	N_o	n_t	k	t_g	k	t_g
Mar.	5,200	17,000	0.022	28		
	3,000	26,600	0.046	15		
	8,400	63,200	0.042	17		
	4,200	204,000	0.081	9	0.048	19
Nov.	190	2,710	0.055	13		
	2,720	11,360	0.030	23		
	480	9,120	0.061	11		
	880	2,400	0.021	34	0.042	20
Dec.	2,100	7,200	0.026	27		
	1,200	14,000	0.051	14		
	1,800	5,800	0.024	29		
	1,600	4,800	0.044	16		
	2,600	4,000	0.009	78	0.031	33

7g. *Navicula* spp

n_o	n_t	k	t_g
320	3,500	0.050	
280	800	0.022	
400	1,120	0.021	
1,120	6,400	0.036	
2,000	8,400	0.030	
1,800	5,600	0.024	
800	8,000	0.048	
Average		0.033	21

Growth and productivity characteristics of a green flagellate, TETRASELMIS GRACILIS Kylin.

It has been pointed out by Braarud (1961) that although studies on primary production in the sea by ^{14}C method have given valuable results, the problems related to the actual behaviour of the species which are responsible for the observed production have not been investigated. Ever since the classic work on diatom cultures by Marshall and Orr (1928) and Jenkin (1937) there have been several attempts to study the influence of such environmental factors as salinity, temperature, light and inorganic nutrients on the growth and photosynthesis of phytoplankters. In addition, there have been a number of kinetic studies on unicellular algae in culture (cf.Strickland, 1960). It is also possible to find answers to the many problems facing the field ecologist in the microcosm of the culture flask. For example, the phenomenon of succession in the Cochin backwater has been found to be due to the varying nutrient requirement of the different phytoplankters (Qasim, 1973).

Unicellular algae grown in culture show a variable lag interval, succeeded by a vigorous logarithmic growth phase, culminating in the cessation of growth brought about by nutrient depletion or by metabolities which inhibit further growth

(Kain and Fogg, 1958). This study of such a growing culture of <u>Tetraselmis gracilis</u> from the period inoculation for over a month gives the growth trend and productivity characteristics and also the comparative values obtained by oxygen and ^{14}C methods.

<u>Tetraselmis gracilis</u>, a commonly occurring flagellate in the coastal waters of Cochin is an unicellular green and phototactic flagellate with an oval shape, having a diameter of 6 μ. Reproduction takes place by longitudinal fission of the protoplasts into two daughter cells. Their phototactic behaviour was found useful for their isolation, and they were cultured in Miquel's medium (modified by Ketchum and Refield, 1938).

One week old healthy and synchronous culture of 4 ml (all motile) having a concentration of 150,000 cells/ml were inoculated into 3 litres of the medium taken in 5 litre conical flasks and grown in diffused daylight at room temperature, under aeration. Aliquots of the culture were taken every alternate day and determinations were made of chlorophylls <u>a</u> and <u>b</u> by the method of Parsons and Strickland (1963) using a Unicam Spectrophotometer. The carbon production was measured by the oxygen and ^{14}C techniques. The experimental time was 3 hours at 20 klux. Activity of filter was determined on a Geiger Counting System (Electronics Corporation of India) having a counting efficiency of 3.2%. The growth parameters were measured for over a month totalling twenty seven observations (Table 8).

Growth trend in Tetraselmis:

From an initial concentration of 200 cells/ml it increased to 1000 cells/ml by the second day and then to 30,000 cells/ml on the third day. By the fifth day, the concentration reached 100,000 cells/ml. The exponential growth phase reached its climax by the seventh day when the concentration was 330,000 cells/ml.

The highest k value of 0.05 was obtained on the fifth day when the mean generation time, t_g, was 14 hours. From then on there was a steady decrease in the k value and a progressive increase in the mean generation time, t_g. The k value dropped to 0.01 by the twenty fifth day and thereafter continued at this level till the thirty fifth day. The generation time, t_g, meanwhile increased to 70 hours. Though the cell number/ml exceeded 1 million by the end of this period, the decrease of the k value and the increase in the t_g suggest that the cells were no longer actively dividing due to nutrient deficiency. Ketchum (1939b) has shown that phosphorus becomes a limiting factor in dense cultures of Nitzschia closterium. Repeated additions of nutrients could prolong the exponential phase of growth in cultures, as shown by Raymont and Adams (1958).

The t_g value for a similar chlorophycean flagellate *Dunaliella euchlora* is 12 hours (McLeod, 1957). Wood (1958) remarks that in tropical forms *k* values will be higher than that in temperate forms, but such variation is not observed in this species.

Chlorophylls in relation to production:

In Chlorophycean algae chlorophyll *a* forms a major pigment and *b* forms only a minor component. As the chlorophyll content is an index of the photosynthetic potential, and its increase represents the multiplication and growth of the alga, simultaneous measurements of cell counts and chlorophylls *a* and *b* were measured. Chlorophyll *a* values showed a progressive increase from 550 µg/l representing a concentration of 33×10^4 cells. The maximum value obtained by the end of the month was 3116 µg/l representing 1×10^6 cells. Chlorophyll *a* per unit of 1000 cells thus indicate an increase from < 2 µg to > 3 µg. This increase with the growth of the culture may be due to chlorophyll released by rupture of older cells.

Several estimates in phytoplankton have been made of the number of cells that contain unit weight of chlorophyll. No average figure has any significance. Strickland (1960) gives the following expression:

No. of cells = $F \times 10^6$ x mg chlorophyll

Accordingly the value for F in Tetraselmis in the initial period of growth is 0.6 which decreases with the age of the culture. If chlorophyll a and b are together considered F is 0.4.

The variation in values of chlorophyll b per litre ranged from about 300 µg representing 35×10^4 cells to 11000 µg for 1×10^6 cells. The mean value for 1000 cells of chlorophyll b is 1.1 µg. The ratio of chlorophyll a to b was uniformly constant from the end of the first week (when measurements of pigments were commenced) to the end of the experiment.

In nature, the concentration of chlorophyll per unit volume of water for the upper part of the euphotic zone varies throughout the day more or less in accordance with the variation in the rate of potential photosynthesis. This phenomenon is observed even in bodies of water enclosed in transparent plastic bags (Yentsch and Ryther, 1957). In the experimental culture light was fairly constant without marked diel variation (about 3-4 klux). Hence the variation in the chlorophyll concentration can be fully attributed to the multiplication, growth and subsequent decline of the cells.

The gross carbon values per litre per hour ranged from 0.07 to 0.79 mgC measured by the oxygen technique, and from

0.03 to 0.34 mgC per hour by ^{14}C technique. When the production rate per unit number of cells (1000) was calculated from the oxygen change, the highest rate observed was during the exponential phase and thereafter decreased steadily. This confirms the earlier observation that the increase of chlorophylls in the culture per unit volume as well as per unit number of cells represent some of the liberated chlorophylls which are no longer photosynthetically active.

The ^{14}C technique registered lower values constantly in all the observations (Table 8), being generally 50% or even less. The difference may be the cumulative effect of the various factors such as: nutrient depletion, a higher PQ of the culture, secretion of labelled carbohydrate in dissolved form, or the rupture of the fragile membrane during filtration. Due to such large differences ^{14}C values may not reflect the real production in measurements with Tetraselmis.

The gross and net production values given in Table 8 were computed using the formula given by Steemann Nielsen (1964). The respiration rate has been observed to be about 30%. By extrapolation of the curve showing the rate of net photosynthesis as a function of light intensity, as given by Steemann Nielsen and Hansen (1959), the rate of respiration deduced was 36% (Fig.24).

Thus it would appear that some of the discrepancy in the oxygen and ^{14}C values is brought about by the inherent nature of the constituent organisms in the population. When fragile flagellates dominate in the plankton ^{14}C measurements would naturally record lower values and an arbitrary correction of 10% for respiration would not be adequate to compute gross production.

Table 8. Daily variations in cell numbers, chlorophylls and rate of primary production

Cells/ml	Chlorophyll concentration			Production				
	a (µg/1000 cells)	b	a:b	Oxygen method gross (mgC/1/hr)	net	per 1000 cells µg/l/hr	^{14}C method gross mgC/1/hr)	net
200	—	—	—	—	—	—	—	—
1000	—	—	—	—	—	—	—	—
30000	—	—	—	0.07	0.03	2.4	0.03	0.02
40000	—	—	—	—	—	—	—	—
100000	—	—	—	0.23	0.15	2.27	0.06	0.06
330000	1.66	0.82	2.3:1	0.31	0.24	0.93	0.14	0.13
280000	—	—	—	—	—	—	—	—
370000	2.08	0.88	2.3:1	—	—	—	0.22	0.20
390000	2.15	0.89	2.3:1	0.41	0.35	1.04	0.19	0.17
410000	2.61	1.08	2.3:1	0.52	0.41	1.26	0.20	0.18
440000	3.09	1.48	2.3:1	0.62	0.46	1.42	0.28	0.25
490000	3.12	1.08	2.3:1	0.46	0.39	0.94	0.22	0.20
520000	—	—	—	—	—	—	—	—
600000	2.28	1.03	2.3:1	0.46	0.36	0.77	—	—
740000	—	—	—	—	—	—	—	—
760000	2.63	0.85	4:1	0.54	0.44	0.71	0.34	0.30
770000	2.91	1.03	2.3:1	0.79	0.60	1.02	0.15	0.13
730000	—	—	—	—	—	—	—	—
730000	3.18	1.26	2.3:1	0.71	0.57	0.97	0.20	0.18
730000	—	—	—	—	—	—	—	—
730000	3.24	1.28	2.3:1	0.18	0.10	0.25	0.09	0.08
800000	3.24	1.32	2.3:1	0.25	0.19	0.32	0.18	0.16
900000	3.35	1.32	2.3:1	0.60	0.40	0.66	0.13	0.12
1030000	—	—	—	—	—	—	—	—
1070000	2.91	1.03	2.3:1	0.66	—	0.61	0.17	0.15
1070000	—	—	—	—	—	—	—	—
970000	3.21	1.08	2.3:1	0.64	—	0.66	0.26	0.24

SEASONAL AND REGIONAL VARIATION IN PRIMARY PRODUCTION IN THE INDIAN SEAS

Out of the 307 million hectares of shallow water areas in the Indian Ocean 40 million hectares are continuous to the coast line of India. Of this about 17.5 million hectares are within 50 m depth contour and the rest between 50 and 200 m. The major pelagic and demersal fishery resources are taken at present within the 50 m depth and as such the productivity of these areas is of immediate interest. The west coast of India has a broader shelf and so 11.5 million hectares of shallow (< 50 m depth) area are on the west coast and 6 million hectares on the east coast. Inspite of some variability due to seasonal fluctuation this area, in general, is very productive as may be seen from the following account.

Gulf of Mannar:

The magnitude of production and seasonal variation have been computed mainly from light and dark bottle experiments. The daily gross production per unit volume of water was separately calculated for surface and bottom (For most part of the year the entire column is within the euphotic zone). The consumption was calculated by the decrease in the dark bottle and net community production by deducting the respiration from the gross and also by the net increase in the light bottles. The daily values were integrated to obtain the production per unit area per day and by multiplying the average daily values by the number of days per month total monthly production was obtained. From that the annual production was computed.

Table 9. Variation in average values (per unit volumes) of gross production, consumption and net community production as gross minus respiration (1) and net increase in light bottle (2), at Station G1.

Period	Gross production mg C/m^3/day	Consumption mgC/m^3/day	Net community production (mgC/m^3/day) 1	2
January	280.0	45.6	234.4	233.3
February	203.7	61.8	141.9	141.9
March	254.5	141.3	113.2	102.1
April	324.7	128.1	196.6	196.3
May	370.4	177.1	193.3	198.3
June	117.7	95.1	22.6	22.5
July	77.4	49.5	27.9	27.9
August	95.7	41.4	54.3	45.7
September	127.4	127.4	00.0	54.0
October	136.5	86.5	50.0	55.1
November	171.5	60.7	110.8	111.0
December	240.6	66.6	174.0	234.3

Annual gross production per unit volume = 72.10 gC/m^3
" consumption " = 32.92 " (45.6%)
Annual community production " = 39.18 "

Table 10. Average annual production per square metre of the sea surface for the respective stations

Station	1958	1959	1960	1961
G1	361	379	399	-
G2	-	103	100	142
G3	-	341	387	797
G4	-	261	200	176
G5	-	544	483	729
G6	-	594	544	641

At station G1, there were two peaks of production - one in April-May and the other in the latter part of the year. During the first year of the study the mean monthly values ranged from 77 mgC/m^3/day in July to 350 mgC/m^3/day in May with an average of about 200 mgC/m^3/day. In the second year the values for the corresponding period were 124 mgC/m^3/day in July and 388 mgC/m^3/day in April. The values for the surface and bottom were more or less of the same order of magnitude. The annual gross production for station G1 at the surface was 72.10 gC/m^3 and consumption

32.92 gC/m^3 leaving an annual net community production of 39.18 gC/m^3. The total consumption amounted to 45.6% of the gross production (Table 9).

The column production for station G1 ranged from 1.85 gC/m^2/day in May to 0.39 gC/m^2/day in June. The annual production for the three years of study were 361, 379 and 399 gC/m^2. (Table 10). Station G2 showed a comparatively lower rate whereas G5 and G6 had a higher rate. The mean value for all the 6 stations for the three years of complete observation was 400 gC/m^2/year.

^{14}C experiments were conducted only at random along with oxygen experiments. In all the experiments conducted in the shallow waters rates of production at the surface were higher than at the bottom (297 to 438 mg/m^3/day at the surface). But at a deep water station off Tuticorin, where the euphotic zone extends to 45 metres, the maximum rate per unit volume was at 10 metres - 372 mgC/m^3/day (Fig.20). The column production at this station in August, which was not particularly a period of high production, amounted to 6.8 gC/m^2/day.

Dark uptake was 1% at the surface and 2% at the bottom. Rate of production in samples taken at noon and incubated till sunset was only one-fourth of that taken at sunrise for the surface samples, but was nearly the same for the bottom samples. Though there has been a marked depression thus at noon, the afternoon samples registered a steep rise. In this connection it has been pointed out by Strickland (1965) that observations in the Pacific at 50°N have indicated that the best approximation to the daily rate is given by twice the photosynthesis measured in one experiment lasting from dawn to solar noon. Twice the value from mid-day to dusk is markedly lower and the worst results are obtained from a full day of incubation or from extrapolations of experiments of short duration made in the morning or afternoon.

Palk Bay:

^{14}C experiments were conducted in Palk Bay from 1961 to 1964 at different stations (P1-P6) at different periods. The values integrated for depth ranges of 8, 10 and 12 metres depending on the station of observation are pooled and given in Table.11.

Table 11. Rate of production per unit volume at different depths and per unit area of sea surface in Palk Bay.

Date	Station	Depth in m	Production mgC/m³/day	gC/m²/day
13-3-1961	P_2	0	36.5	
		5	40.5	
		10	53.3	0.4

(Contd Table 11)

1	2	3	4	5
12-6-1961	P_2	0	638.0	
		5	489.0	
		10	143.0	4.4
26-6-1962	P_2	0	1061.5	
		10	153.2	6.0
4-7-1962	P_2	0	2341.9	
		5	545.0	
		10	52.5	8.7
9-7-1962	P_2	0	1375.2	
		5	53.3	
		10	37.5	3.8
11-7-1962	P_6	0	774.3	
		6	147.2	
		12	8.9	3.2
18-7-1962	P_4	0	543.2	
		6	250.9	
		12	38.7	3.2
20-2-1963	9°24'N, 79°13'E	0	20.4	
		5	10.2	
		10	1.8	0.1
21-2-1963	9°44'N 79°16'E	0	42.2	
		5	12.4	
		10	2.6	0.2
11-6-1963	P_2	0	129.1	
		4	135.2	
		8	104.1	
		10	4.9	1.0

(Contd. Table 11)

1	2	3	4	5
17-6-1963	P_2	0	203.2	
		4	320.4	
		8	149.8	
		10	62.4	2.2
26-8-1964	P_1	0	288.5	
		4	165.1	
		8	78.9	1.4
26-8-1964	P_1	0	341.9	
		8	77.7	1.68
2-9-1964	P_1	0	156.9	
		8	119.9	1.11
-do-	P_2	0	144.8	
		8	112.3	1.03
16-9-1964	P_1	0	166.0	
		8	88.7	1.02
9-10-1964	P_2	0	170.0	
		5	155.3	
		10	37.9	1.30
13-10-1964	P_1	0	157.0	
		3.5	106.6	
		7	52.4	0.74
19-10-1964	P_2	0	181.2	
		5	146.8	
		10	44.4	1.29
		D	1.4	
22-10-1964	P_2	0	225.84	
		5	151.20	
		10	37.32	1.41

Table 12. Mean integrated values of Primary production in Palk Bay per unit area (i - interpolated values)

Month	Production $gC/m^2/day$
January	0.45 (i)
February	0.15
March	0.40
April	1.40 (i)
May	2.40 (i)
June	3.40
July	4.70
August	1.54
September	1.05
October	1.19
November	0.95 (i)
December	0.70 (i)

Annual gross production

\- 561 gC/m^2

For the months when data are not available interpolated values have been taken (Table -12).

From the low rate of < 0.5 gC/m^2/day during January-March, the rate of primary production steadily rises to 4.7 gC/m^2/day in July. From then the rate drops to 1.5 gC/m^2/day by August and continues at a steady rate of 1 gC/m^2/day till the month of December. Thus the primary production in Palk Bay is conspicuous with a single peak in July and more or less maintain a high rate of >1.0 gC/m^2/day from April to October. The annual production is computed at 561 gC/m^2 which makes the region comparatively richer than all the inshore environment studied in the Indian seas.

Palk Bay being a sheltered area with a larger autochthonous stock of phytoplankton, higher level of nutrients and better light penetration could sustain a high rate for a comparatively longer period. The period of low production coincides with the period of north-east monsoon when the sea is rough.

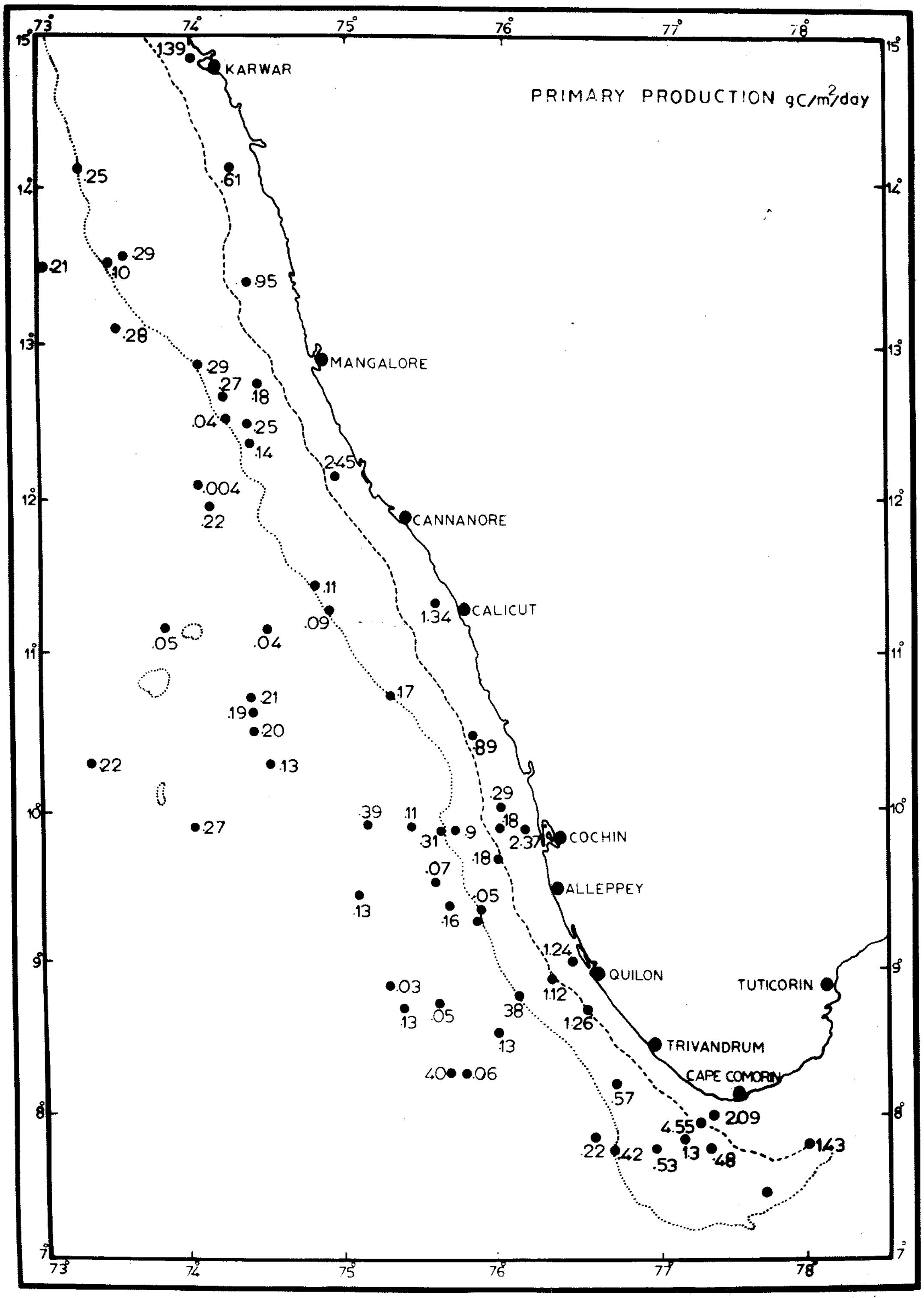
It is also noteworthy that during the period of intense phytoplankton production in July the surface production reached an exceptionally high value of 2340 mgC/m^3/day. Rate of production fell rapidly within 5 metres but there was appreciable production even at 10 metres. The column production is usually between 3 to 6 $gC/m^2/day$ and once even attained the highest figure of 8.68 $gC/m^2/day$, which seems to be the highest rate ever recorded from anywhere in the Indian Ocean region.

In Walvis Bay, though Steemann Nielsen and Aabye Jensen (1957) observed a record production of 6600 $mgC/m^3/day$ in the surface waters due to the presence of a huge amount of naked dinoflagellate, the column production amounted to 3.8 $gC/m^2/day$ as the euphotic zone was only 0.8 metre deep. The maximum value recorded from the Arabian Sea was 6.4 $gC/m^2/day$ off the coast of Saudi Arabia Ryther _et al_. (1966).

<u>South-west coast of India and the Laccadive Sea</u> (Fig.9)

In the inshore areas on the south-west coast of India values over 2 $gC/m^2/day$ are obtained within 50 m depth during monsoon period. Over the Wadge Bank off the southern tip of the Peninsula, at a station 38 m deep, the production rate was 2.09 $gC/m^2/day$ in June. Just below the surface the rate per unit volume was 12 $mgC/m^3/hour$, suggesting a constant replenishment of nutrients. By using artificial light of about 20 klux rates as high as 52 $mgC/m^3/hour$ have also been observed with surface water during monsoon period at a station south of Mangalore (12°08'N). The

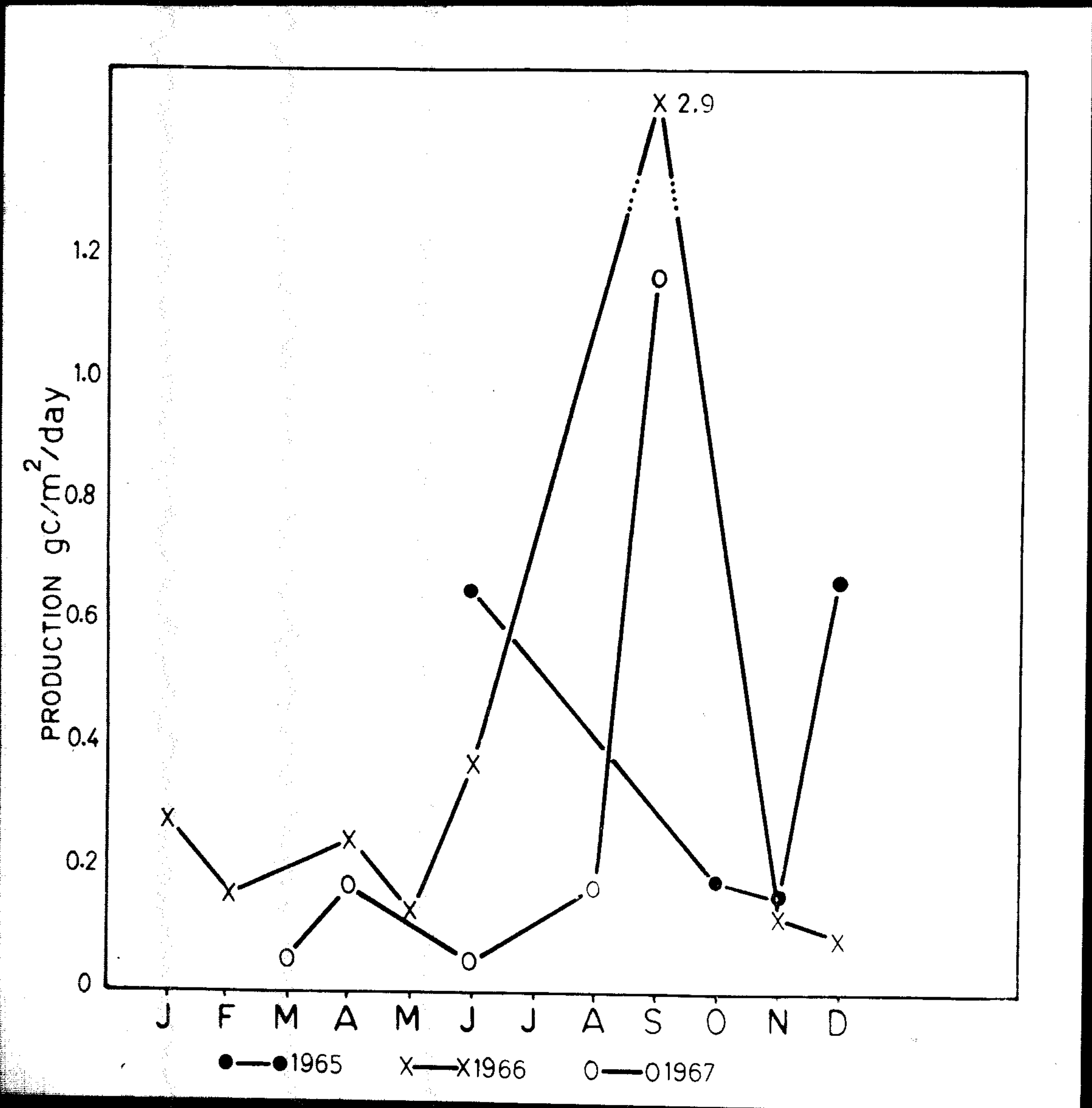
Fig.9. Stations occupied on the south-west coast of India and the Laccadive Sea during 1965-68 with the daily rates of primary production for the water column.


PRIMARY PRODUCTION gC/m²/day
KARWAR
MANGALORE
CANNANORE
CALICUT
COCHIN
ALLEPPEY
QUILON
TRIVANDRUM
TUTICORIN
CAPE COMORIN

highest value of 4.55 $gC/m^2/day$ for the west coast was observed at a station on the Wadge Bank in September. The mean monthly values for the three-years are shown in Fig.10.

Though this rate of production is high it is not unusual for the shelf areas of the Indian Ocean. During the cruise of ANTON BRUUN, values exceeding 1 $gC/m^2/day$ were observed at 8 stations of which three stations had values exceeding 3 $gC/m^2/day$. Radhakrishna (1969) observed in the shelf waters off Alleppey on the west coast during the post-monsoon period values ranging from 0.38 $gC/m^2/day$ to 1.11 $gC/m^2/day$ with an average of 0.81 $gC/m^2/day$. Cushing (1971) also points out Kabanova's observation about intense production off the Malabar coast, which extended seawards for a considerable distance. The observations of Subramanyan (1959) from standing crop measurements also confirm the high productivity of the inshore regions of the south west coast. The data presented in Table 13 and the summary of values for the different depth zones (Table 14) indicate that the level of organic production is high towards the coast, becomes less towards the edge of the continental shelf and is least outside the shelf, except in regions of deep water ascent (Kabanova, 1961) and around

Fig.10. The seasonal variation in values of
production on the west coast based
averages.


X 2.9
1.2
1.0
0.8
0.6
0.4
0.2
0
PRODUCTION gC/m^2/day
J F M A M J J A S O N D
●—● 1965 X—X 1966 O—O 1967

the Laccadive Islands (Prasad and Nair, 1962). Based on the observations made so far the annual gross production for the inshore region within 50 metres depth comprising a total area of 1,14,520 square kilometres has been computed as 50 x 10^6 tons of carbon.

For the zone between 50 m depth and the edge of the continental shelf the average rate is 0.47 gC/m^2/day which is moderately high. The annual gross production would amount to 170 gC/m^2 and for 1,68,790 sq.km. of the shelf area between 50 and 200 metres the total production has been computed as 30 x 10^6 tons.

Table 13. Mean monthly production on the west coast of India within 50 m depth and the annual gross production computed from weighted averages.

Month	rate of production gC/m^2/day	Annual production (gross) gC/m^2/year
January	0.29	
February	0.18	
March	0.13	
April	0.72*	
May	1.40*	
June	2.09	
July	1.45	
August	0.61	
September	1.46	
October	1.36*	
November	1.22*	
December	1.06	453

*Interpolated values

Table 14. <u>Summary of primary production values on the west coast for the different depth zones in gC/m2/day and gC/m2/year.</u>

Up to 50 m				50 to 200 m				> 200 m			
of ns.	Total	Average	Annual	No. of stns.	Total	Average	Annual	No. of stns	Total	Average	Annual
3	28.47	1.24	453	23	10.91	0.47	172	41	7.21	0.18	66

Mud Bank at Alleppey:

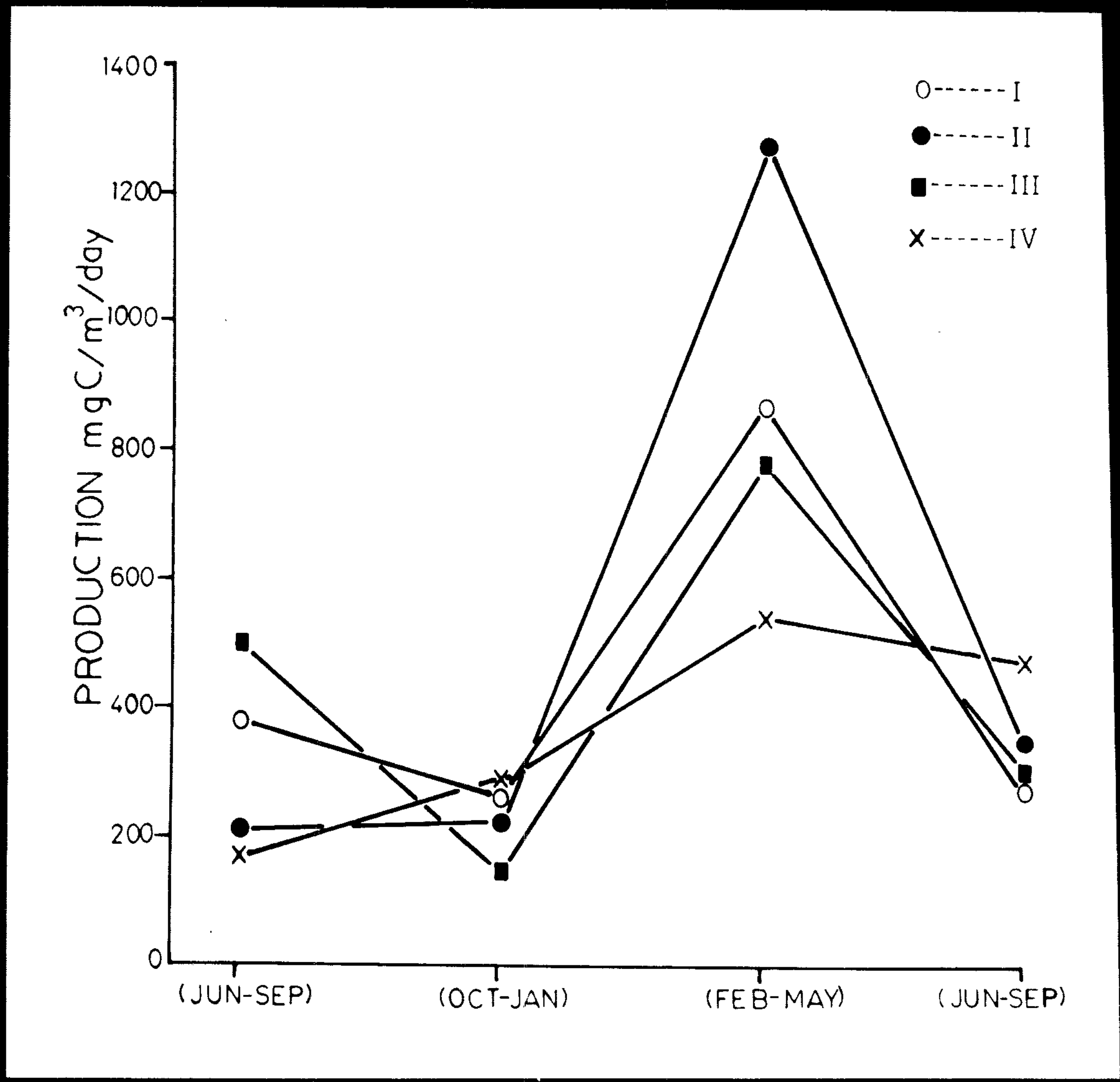
During the south-west monsoon, along the southern section of the west coast of India, there is the periodic formation of mud banks known in local parlance as 'Chakara'. This herald a spell of hectic activity to thousands of fisherfolk, who are otherwise kept away from their occupation by the choppy monsoon seas. The areas of mud banks provide safe operation for the boats in an otherwise surf-ridden coast and yield a bountiful harvest of oil sardine and the highly priced prawns. In view of the impact that the mud banks make on the economy of the fishing community, the Central Marine Fisheries Research Institute initiated a concerted study in June 1971 to augment the meagre data available regarding their ecology and productivity. This account of primary production and related properties of the Alleppey mud bank forms part of it.

The most important and well-known mud banks are at Narakkal, just north of Cochin, off Alleppey and two smaller banks at or near Calicut (Kozhikode). The mud banks at Calicut and Alleppey are of a shifting type. The earlier accounts on the mud banks are those of Bristow (1938), ~~Damane et al.(1938)~~, Seshappa (1953), Seshappa and Jayaraman (1956), Damodaran and Hridayanathan (1966), Nair *et al*.(1966), Rao (1967), Varma and Kurup (1969). But none of these authors has dealt with the productivity.

Fortnightly or monthly collections of water samples from the surface and bottom were incubated with 5 μc of $Na_2{}^{14}CO_3$ under constant light of 20 klux and the potential productivity was determined which was converted into the daily rate of primary production as given before. The results are presented in Figs.11 and 12 for the surface and bottom samples for the four stations. Total phytoplankton counts taken after settling the samples and chlorophyll measurements are given in Table 15.

The results show that there is a great amount of seasonal and spatial variability even within a limited area, which is not in consonance with the rate for the west coast as a whole. This is probably because of the special conditions existing in this environment especially during the season of the mud bank, which is between June to September. At this time the fine mud present in the area is churned up giving an oily appearance to the water and also releasing a considerable quantity of the nutrients.

Fig.11. The rates of potential productivity derived from tank experiments using the surface wat of the mud bank. I to IV are for the respec- tive stations of observation.


1400
1200
1000
800
600
400
200
0
PRODUCTION mgC/m^3/day
(JUN-SEP)
(OCT-JAN)
(FEB-MAY)
(JUN-SEP)
O------I
●------II
■------III
X------IV

11

Fig.12. The rates of potential productivity deri
from tank experiments using the water fr
the bottom of the mud bank area. I to IV
for the respective stations of observati
Grouping of data as in surface samples
(Fig.11).

So the turbidity is very high allowing light penetration to less than a metre during the south-west monsoon period. The highest chlorophyll a values are observed during the June-September period. The potential productivity is lower for the surface samples as compared to the bottom samples. It is likely that the chlorophyll values do not represent a true index of standing crop in view of the presence of non-living chlorophyll released from the mud by wind and wave action. Low assimilation ratios (mgC/hr/mg chl a), except during February-May when stable conditions prevail, also indicate this fact (Table -15).

The total cell counts during the monsoon season are considerably influenced by the presence of Noctiluca, both the pink and green forms. The phenomenon of discoloured water caused by pink Noctiluca during June-September period along the west coast has been observed by Subrahmanyan (1959).

As may be seen from Table 15 the rate of potential assimilation is uniformaly high in the mud bank area averaging 35 mgC/m^3/hour with the maximum potential productivity during the February-May period. This high rate is maintained by a constant replenishment of nutrients from the nutrient-rich bottom. The potential productivity is translated into real productivity when conditions for light penetration are favourable. At other times the area forms a rich forage ground for the pelagic fishes and prawns which accounts for the abundant catch at a season when rough conditions prevail outside the area of the formation of mud bank.

Table 15. Productivity parameters of the Alleppey mud bank. Averages for the mud bank season (June-September) and those preceding and succeeding seasons (pooled for the four stations)

Period	sample	Chlorophyll a mg/m^3	Phytoplankton cells/l	Potential assimilation mgC/m^3/hour	Assimilation ratios
June-Sept.	S	21.80	272,700	26.06	1.2
"	B	22.16	139,300	58.43	2.8
Oct.-Jan.	S	5.51	161,000	19.13	3.5
"	B	8.08	129,000	11.55	1.4
Feb.-May	S	3.11	171,000	72.06	23.2
"	B	3.19	136,700	34.51	10.8
June-Sept.	S	10.81	387,000	29.00	2.7
"	B	13.77	269,500	26.34	1.9

S- Surface B- Bottom

Indian Ocean

Apart from the data so far collected from the seas around India (Table 16) the results of measurements by GALATHEA (Steemann Nielsen and Aabye Jensen, 1957), VITIAZ (Kabanova, 1961), AFRICANA II (Mitchell-Innes, 1967) and data sheets of ANTON BRUUN and DIMANTINA have been taken for computing the productivity of the Indian Ocean in general. For the oceanic regions the available data have been pooled and the average was taken for every 10° square. Isolines were constructed using these values.

The measurements of primary production in the Indian Ocean by GALATHEA were the first ones made with ^{14}C. All stations at middle latitudes in the western part outside the continental shelf were characterized by a production rate between 0.1 and 0.2 $gC/m^2/day$, the value normally found in tropical and subtropical oceanic regions in the absence of any pronounced admixture of nutrient-rich water from below. Over the shelf off Beira the average was 0.51 $gC/m^2/day$. On the Agulhas Bank, water from the lower boundary of the photosynthetic zone showed three and half times the rate of production from that of the surface under constant illumination, indicative of a distinct ascent of nutrient-rich water to the photosynthetic layer (Steemann Nielsen and Aabye Jensen, op.cit.) In the South Equatorial

Current a relatively high production rate, 0.22-0-23 gC/m^2/day, was found. The coast of Ceylon has a high production rate. Very high values were observed southeast of Java, where upwelling, fairly high concentration of inorganic phosphate at the bottom of the euphotic layer and a high plankton biomass have been demonstrated by Wyrtki (1962). Summarizing all the measurements in the equatorial current systems of the Indian Ocean, Steemann Nielsen and Aabye Jensen (1957) concluded that the rate of production is moderately high in the whole region of the equatorial current systems and in restricted areas very high production is found. The absolute values, however, have to be enhanced by 1.47.

Kabanova (1961, 1968) reported that primary production in the open part of the ocean was low and did not exceed 0.01-0.03 gC/m^2/day. An increase in the value of primary production was observed in coastal waters and in the zones of ascent of deep water. In the Banda Sea the production reached 0.024 gC/m^2/day, while on the Australian shelf the value increased up to 0.45 gC/m^2/day. In the African Madagascar region it was 0.072 gC/m^2/day.

For the western Indian Ocean, Ryther et al.(1966) observed two large areas of low productivity, one to the north extending from 80° to nearly 60° E long[illegible] from the Indian Continent to about 5°S latitude and another from 10° to about 40°S latitude and from 80° E nearly to the African coast south of Madagascar. ANTON BRUUN measurements do not include any from the coast. But measurements given earlier indicate that the level of production is high towards the coast and becomes less seaward. The annual rate of gross production is ca 400 gC/m^2 practically anywhere on the shelf within 50 metres depth, 150 - 200 gC/m^2 between 50 and 200 metres and 50 gC/m^2 outside the shelf.

North of the equator Ryther *et al.* (*loc.cit.*) observed values of primary production increasing to the north and west reaching exceptionally high values off the coasts of Saudi Arabia and Pakistan. The average for 23 measurements in that region was more than 1.0 gC/m^2/day observed off the south-eastern tip of Arabia. Based on these measurements, Ryther *et al.*(1966) calculated that for the western Indian Ocean, where the ANTON BRUUN survey was carried out for an area of 23 x 10^6 sq.km (about half of the Indian Ocean region now being considered or one-third of the Indian Ocean as conventionally mentioned), the annual productivity is 3 x 10^9 tons of carbon which gives an average of 0.35 gC/m^2/day. But because of the great contrast in the relative productivity in this region the average value has not much significance. About half of the total production occurred in 20% of the area surveyed. The observations in the western half of the Arabian Sea are summarized by Wooster et al. (1967).

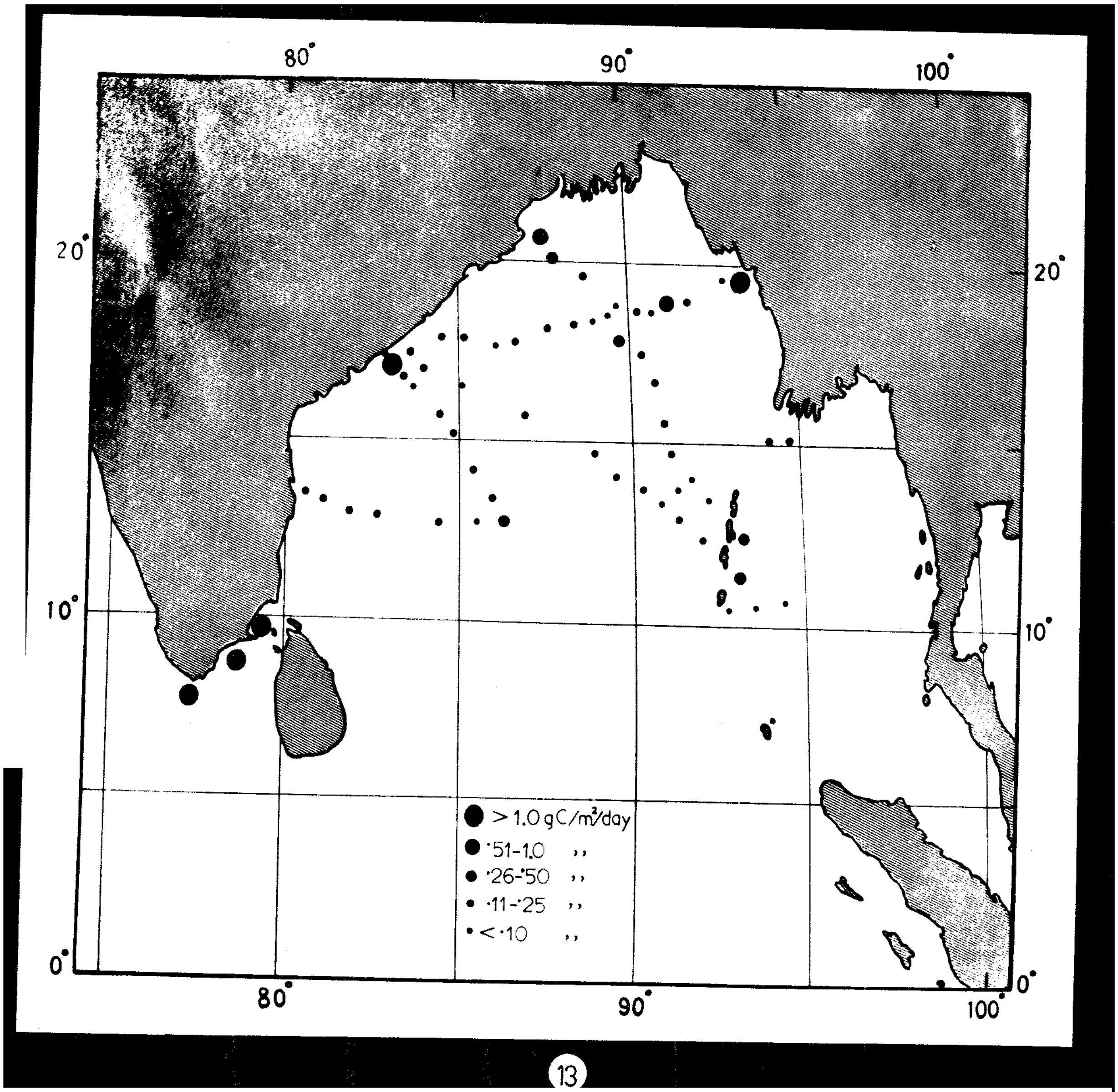
Mitchell-Innes (1967) found for the region off South Africa, between latitudes 26° and 47°S, values ranging from 0.3 to 1.08 gC/m^2/day. High productivity was observed ($>$ 0.5 gC/m^2/day) in Delgoa Bay and off Port Elizabeth. Burchall (1968 [illegible]) observes values ranging from 0.02 to 0.94 gC/m^2/day) in the Agulhas Current region off Natal. Areas of high primary production were located in the vicinity of the continental shelf and also at the eastern boundary of the Agulhas Current.

The average rate of production for the western half of the Indian Ocean is a little higher than the eastern half being 0.40 and 0.32 gC/m^2/day respectively (80°E longitude is taken as boundary). Hence the annual gross production for the western half comprising 29×10^6 sq.km is 3.83×10^9 tonnes of carbon and for the eastern half comprising 22×10^6 sq.km is 2.67×10^9 tons.

For the Bay of Bengal area much data on the primary production are not available. Though it is a proper part of the Indian Ocean the salinity is relatively low through the supply of fresh water. According to Steemann Nielsen and Aabye Jensen (1957) who provide the first data on productivity from this region, extensive investigations during different seasons are necessary in order to get a true picture of the productivity of the Bay of Bengal, as the monsoon shift has considerable influence on the hydrography and productivity of this area.

Lafond and Lafond (1968) have investigated the water motion during the cruise of R.V.ANTON BRUUN. They report that the duration and intensity of upwelling on both sides of the Bay of Bengal is not as great as in the western Arabian Sea. The areas of highest phytoplankton concentration were near shore on the northern and eastern sides of the Bay where there was replenishment of nutrients due to upwelling. The subsurface water rich in nutrients was found in the northern regions by the GALATHEA Expedition. The depth of euphotic zone was 45-66 metres at the western region and 84-99 metres in the eastern region indicating low productivity (Steemann Neilsen and Aabye Jensen, 1957). The lower transparency in the western part is presumably due to the organic and inorganic material conveyed by the rivers which decrease the rate of photosynthesis per surface area. Fig.13 shows the daily rates of production as reported by GALATHEA and ANTON BRUUN

Fig.13. The rates of primary production in the Bay of Bengal. The values from the Gulf of Mann and Palk Bay on the south-east coast of Ind and the Andaman Sea are based on the candid observation. Rest of the values in the Bay Bengal proper are based on GALATHEA and ANN BRUUN reports.



13

(Steemann Nielsen and Aabye Jensen, (loc.cit.) and Woods Hole Oceanographic Institution Data Sheet, 1964).

Distribution map of primary production given by Kabanova (1968) for the Bay of Bengal during winter indicates values between 0.75-1.45 gC/m^2/day for the south-east coast of India and between 0.38-0.75 gC/m^2/day for the Andaman Sea. Localised high values are found towards the northern end of the Bay of Bengal and in the Gulf of Martaban.

The average value obtained for the shelf is 0.63 gC/m^2/day which is about the value obtained by Steemann Nielsen and Aabye Jensen (1957) at station 303 (20°37'N, 84°30'E) where the depth is 62 m and the euphotic zone 51 m. The observation was in April, which is not the period of high production on the east coast. The results of studies in Palk Bay show that the latter half of the year is characterised by a high rate of production. Kabanova (1968) also reported high production during the north-east monsoon period (October-December) on the Orissa coast, off Sangor Island and between Burma and the Andaman Islands. Outside the shelf the average production is about 0.19 gC/m^2/day.

The annual gross production for the east coast of India on the shelf would amount to 25 x 10^5 tons of carbon or about one-third that on the west coast, which has a broader shelf and more pronounced upwelling.

Allowing 40% of the primary production for respiratory requirement the annual net production for 51×10^6 sq.km of the Indian Ocean is 3.9×10^9 tonnes or about one-fifth of the estimated world oceanic production (Fig.14).

As indicated before the continental shelf has a mean gross production of 0.85 $gC/m^2/day$. In view of an annual gross production of ca. 400 gC/m^2 observed in the coastal regions of the Indian seas the above value is only minimal. Accordingly the annual gross production for 3.1×10^6 sq.km of the shelf areas in the Indian Ocean would amount to 0.93×10^9 tons of carbon, and the net production 0.56×10^9 tons. Approximately 6% of the total area accounts for about 14% of the entire production. These estimates form the general basis for the computation of the potential yield of fish which is given in the last chapter.

Fig.14. Rates of primary production in different [illegible]
of the Indian Ocean. Isolines are based [illegible]
rages from pooled data for every 5° square
Apart from the candidate's, data collected
during the IIOE have also been used to der[illegible]
the average value for each square.

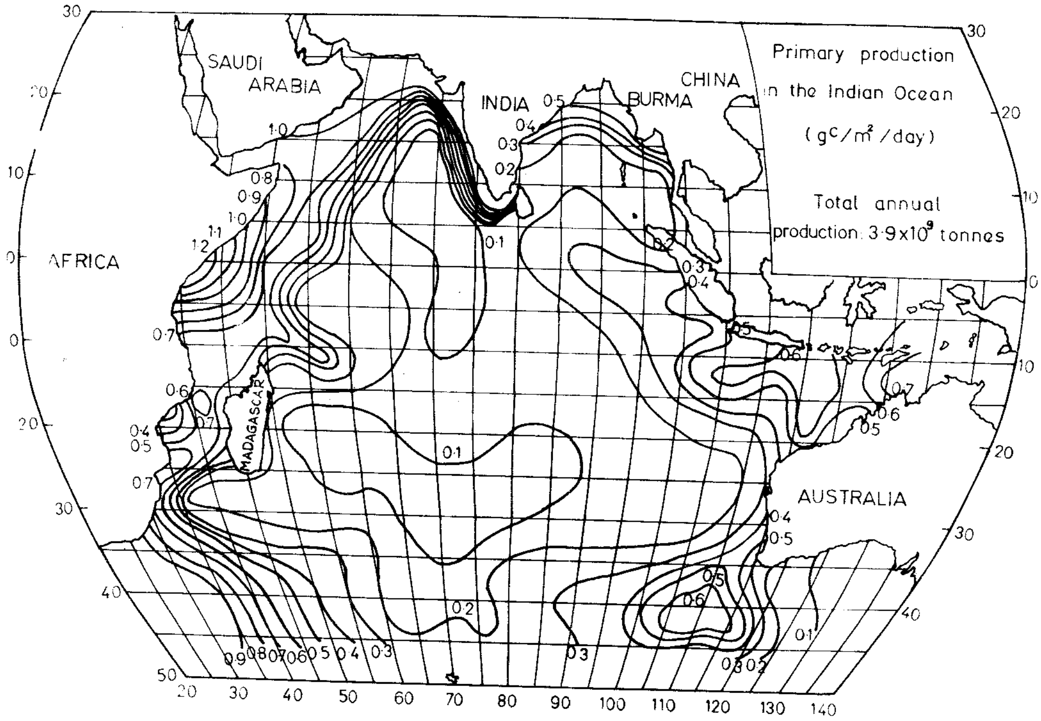

Primary production
in the Indian Ocean
(gC/m² /day)
Total annual
production: 3·9x10⁹ tonnes
SAUDI
ARABIA
INDIA
BURMA
CHINA
AFRICA
MADAGASCAR
AUSTRALIA

Table 16. Values for primary production expressed as $gC/m^2/day$ with station positions, depths and dates.

Date	Position: Latitude N	Position: Longitude E	Depth in metres	Production $gC/m^2/day$
4--6-1965	7°30'	76°00'	1,500	0.33
5--6-1965	8°00'	77°20'	38	2.09
6--6-1965	8°50'	75°20'	1,200	0.03
7--6-1965	9°30'	75°10'	2,000	0.13
12-10-1965	9°50'	75°26'	2,000	0.11
13-10-1965	9°20'	75°39'	400	0.16
14-10-1965	8°44'	75°38'	350	0.05
15-10-1965	7°53'	77°04'	550	0.53
16-10-1965	8°15'	75°47'	1,200	0.06
11-11-1965	7°56'	76°55'	70	0.07
11-11-1965	7°52'	76°38'	900	0.22
12-11-1965	8°32'	76°00'	200	0.13
12-11-1965	8°32'	76°21'	300	0.01
13-11-1965	8°43'	75°26'	800	0.13
15-11-1965	--	--	200	0.50
24-11-1965	11°26'	74°51'	82	0.11
25-11-1965	12°20'	74°40'	58	0.05
25-11-1965	12°40'	74°15'	86	0.27
27-11-1965	13°30'	73°00'	1,600	0.21
27-11-1965	13°30'	73°30'	180	0.10
28-11-1965	12°20'	74°21'	180	0.14
29-11-1965	11°15'	74°34'	1,200	0.04
14-12-1965	11°10'	75°10'	60	0.57
15-12-1965	13°26'	75°10'	40	0.95
16-12-1965	Karwar Bay		7	1.39
19-12-1965	12°30'	74°16'	180	0.04

(Contd. Table -16)

1	2	3	4	5
6--1-1966	14°09'	73°20'	160	0.25
7--1-1966	13°35'	72°55'	1,900	0.35
7--1-1966	13°06'	73°33'	1,800	0.28
8--1-1966	12°27'	74°20'	120	0.25
3--2-1966	9°40'	76°00'	40	0.18
21--4-1966	11°15'	74°49'	260	0.45
22--4-1966	11°40'	76°08'	1,400	0.05
5--2-1966	7°50'	77°11'	300	0.13
7--2-1966	9°30'	75°35'	1,000	0.07
8--2-1966	9°55'	75°09'	2,000	0.39
26--5-1966	12°50'	74°05'	180	0.13
7--6-1966	8°12'	76°44'	80	0.57
8--6-1966	8°46'	76°10'	150	0.38
25--6-1966	13°30'	73°34'	120	0.29
26--6-1966	11°56'	74°11'	1,700	0.22
~~7--8-1966~~	~~8°00'~~	~~77°11'~~	60	~~4.55~~
6--9--1966	9°00'	76°28'	25	1.24
7--9-1966	8°00'	76°58'	90	4.55
8-11-1966	16°30'	73°40'	110	0.11
8-11-1966	16°29'	74°42'	300	0.12
6-12-1966	11°15'	74°55'	120	0.09
9--3-1967	9°21'	75°52'	188	0.05
18--4-1967	10°27'	72°41'	1,600	0.12
20--4-1967	10°43'	74°26'	2,160	0.21
8--6-1967	10°28'	72°42'	1,900	0.06
9--6-1967	11°23'	72°46'	1,900	0.04
6--8-1967	12°44'	74°28'	56	0.18
7--8-1967	14°08'	74°18'	30	0.61

(Contd. Table -16)

1	2	3	4	5
31--8-1967	11°16'	73°50'	2,100	0.05
6--9-1967	9°52'	76°10'	18	2.37
7--9-1967	9°20'	76°51'	50	1.18
7--9-1967	8°42'	76°35'	35	1.26
8--9-1967	8°17'	75°44'	1,400	0.40
9--9-1967	7°45'	77°19'	50	0.48
9--9-1967	7°45'	78°00'	47	1.43
9--9-1967	7°45'	76°43'	183	0.42
10--9-1967	7°27'	77°40'	117	0.95
10--9-1967	7°32'	76°41'	850	0.95
20--7-1968	8°53'	76°21'	50	1.12
21--7-1968	10°29'	75°51'	37	0.89
22--7-1968	11°19'	75°36'	28	1.34
24--7-1968	12°08'	74°58'	37	2.45
10--3-1969	08°12'	78°33'	1,300	0.16
11--3-1969	7°39'	78°15'	630	0.20
13--3-1969	7°25'	77°31'	130	0.36
14--3-1969	7°15'	76°27'	1,550	0.30
8--4-1969	9°28'	75°04'	1,550	0.07
10--4-1969	9°52'	74°08'	1,550	0.27
10--4-1969	10°11'	74°32'	1,550	0.13
11--4-1969	10°17'	73°16'	1,550	0.22
12--4-1969	8°48'	72°24'	1,550	0.10
12--4-1969	8°58'	72°57'	1,550	0.14

(Contd. Table -16)

1	2	3	4	5
13-1-1970	10°00'	76°08'	22	0.29
15-1-1970	9°45'	75°41'	130	0.90
28-1-1970	8°50'	76°20'	58	0.07
29-1-1970	9°15'	75°50'	275	0.09
30-1-1970	9°48'	75°37'	250	0.31
18-3-1970	10°47'	75°13'	200	0.17

FACTORS INFLUENCING PRIMARY PRODUCTION

Light penetration and depth of the euphotic zone

One of the most obvious variable factors influencing primary production is the amount of solar radiation reaching the surface of the sea. The amount of radiation entering the sea surface depends upon the altitude of the sun and changing weather patterns. The intensity of the solar radiation and transparency of the water together determine the depth of the euphotic zone.

Based on lux meter measurements Qasim, Bhattathiri and Abidi (1968) have calculated the avarage radiation falling at Cochin as 250-550 g cal/cm^2/day, the maximum radiation being in January-February and the minimum in July. Unlike in temperate regions the variation between the maximum and minimum amount of radiation is very little here. This has a significant bearing on the seasonal variability of primary production.

It has been pointed out by Steemann Nielsen and Aabye Jensen (1957) that even if the incoming radiation is reduced by 50% the production per unit area would be about 80% of that on a clear day. With a decrease in light intensity of one-third the photosynthetic rate per unit area is about two-third of that measured on a bright day. Only on extremely dark days when there is incessant rain the rate per unit area would be reduced 65% when the light intensity at the surface would be only one-seventh of that on a bright day. Such days are few and far between and as such have no real effect on the overall seasonal production. since the maximum rate is observed in the June-September period, which includes the most cloudy days.

Of more significance than radiation is the transparency of the water, that determines the depth of the euphotic zone which in turn is influenced by the concentration of plankton and the presence of other particulate or dissolved substances which absorb light.

The light penetration and depth of the euphotic zone was studied on the west coast of India and the Laccadive Sea using a Tinsley irradiance meter. It consists of a dark cell mounted on gimbals and a sea cell mounted in a bridle, a galvanometer and ratiometer which measures directly the ratio of the light intensities falling on the sea cell and deck cell that is expressed in percentage. Both the deck cell and sea cell are fitted with Megatron photocell and Chance filters OB2 blue/green which are red-free.

Opal flashed glass placed over the filters diffuse the light falling on the cells and as these are flush with the rim of the deck cell it can receive full 180° of solid angle light.

The sea cell is lowered from the side of the ship and the readings are taken at depths of every two metres marked on the cable. The depth is thus determined by the amount of sea cell cable paid out. Both 'down readings' and 'up readings' are taken. Extinction coefficients are determined by plotting the logarithms of percentage transmission against the depth and also by using the formula:

$$P_5 = \frac{2.3 (\log r_0 - \log r_{10})}{10}$$

where P_5 is the extinction coefficient at 5 m depth, r_0 is the transmission ratio at the surface i.e. the ratiometer readings, r_{10} transmission ratio at 10 m and so on (Gall, 1949). Table 17 A,B,C,D give the light penetration at some stations on the west coast and Table 18 gives the extinction coefficients for different depths at two stations.

Table 17. Light penetration measurements on the west coast using Tinsley irradiance meter.

A. 07°30'N 76°00'E. Depth - 1415 m (June - bright day)

Depth (m)	Down readings % of incident light	Depth (m)	Upreadings % of incident light
0	75	40	3
5	45	30	5
10	25	20	12
20	18	10	25
30	10	5	45
40	3	0	75
50	1		

B. 13°35'N 73°34'E. Depth-120 (January - clear day)

0.5	50	50	3.5
1	45	40	4
2	40	30	9
5	30	20	17
10	20	15	24
15	17	10	28
20	13	5	31
25	12	0	95
30	10		
40	6		
50	3		
55	2		
60	1.5		

C. 11°10'N 75°10'E. Depth - 60 m (December - bright day)

Depth (m)	Down readings % incident light	Depth (m)	Upreadings % incident light
0	50	25	1.6
1	43	20	3
5	20	15	5.5
10	9	10	9.5
15	5	5	20
20	2	2.5	38
25	1.2	1	60
30	0.7	0	80

D. 08°50'N 76°05'E. Depth - 200 m (June, cloudy day)

0	43	12	2
1	32	10	3
4	13	8	5
5	10	6	8.5
6	9	4	13
10	3	2	23
14	1	0	55

Table 18. <u>Light penetration and extinction coefficients</u>

Date	Position	Sonic Depth (m)	Depth of measurement	% of surface light	Extinction coefficient
4-6-1965	7°30'N 76°00'E	1415	5	40	0.138
			15	20	0.033
			25	10	0.026
			35	5	0.120
			45	1.8	0.110
6-1-1966	13°35'N 73°34'E	120	5	30	0.161
			15	20	0.066
			25	12	0.026
			35	7	0.051
			45	4	0.069
			55	1.8	0.069

In coastal and inshore regions transparency is very variable. In the Gulf of Mannar and Palk Bay the compensation depth is at about 6 m indicating a high quantity of suspended matter. On the west coast the euphotic zone is about 50-60 metres in the offhsore waters (Fig.15) and less towards the coast (Fig.16). On cloudy days the euphotic zone shrinks to 14 metres even at the edge of the continental shelf (Fig.17).

Sechi disc was also used for a rough measurement of the depth of the euphotic zone. The sechi disc visibility

Fig.15. Light penetration and depth of the euphotic zone in June on a bright day outside the continental shelf area. Dots - down readings, dashed line - up readings and continuous line the mean of the two.

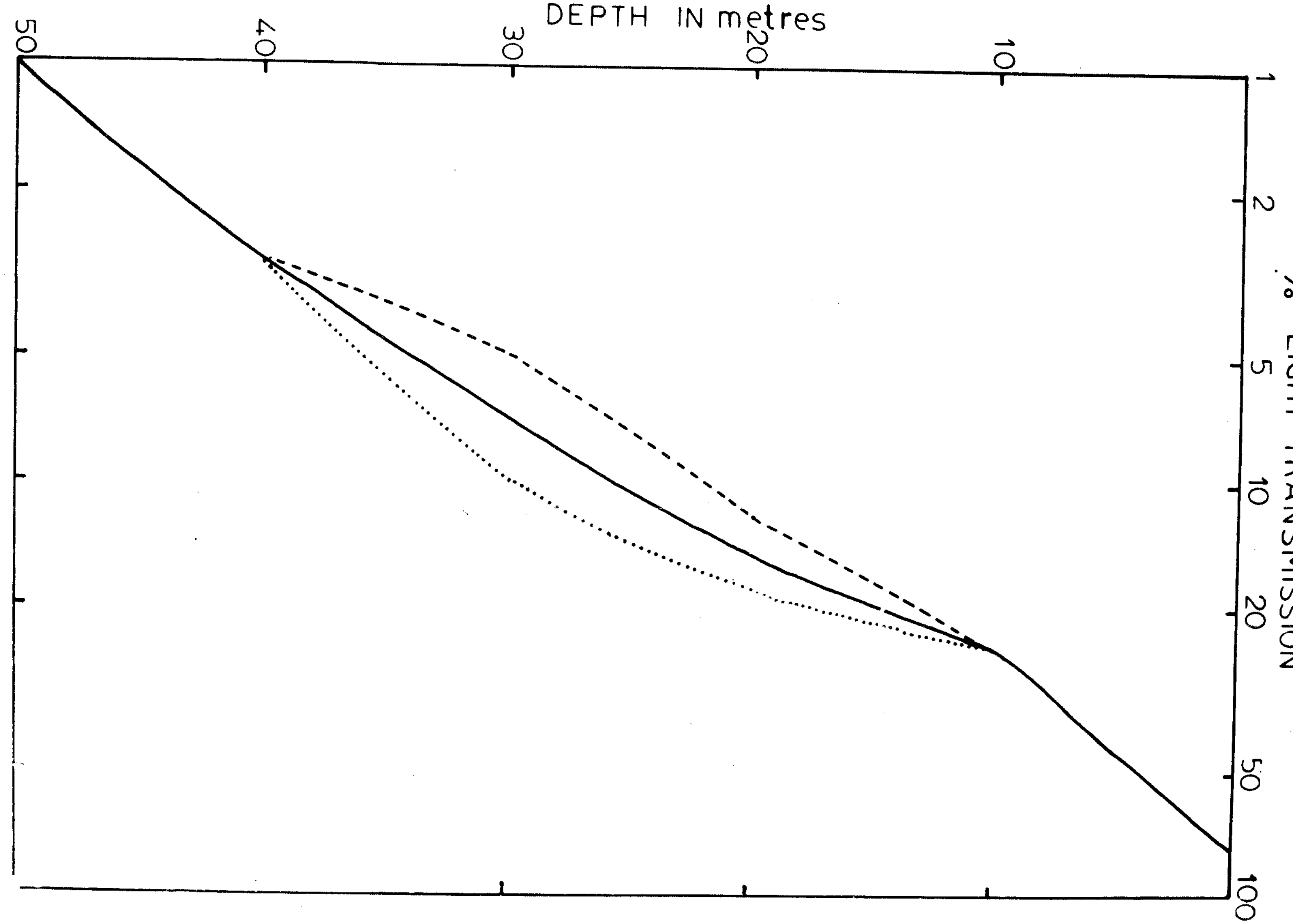
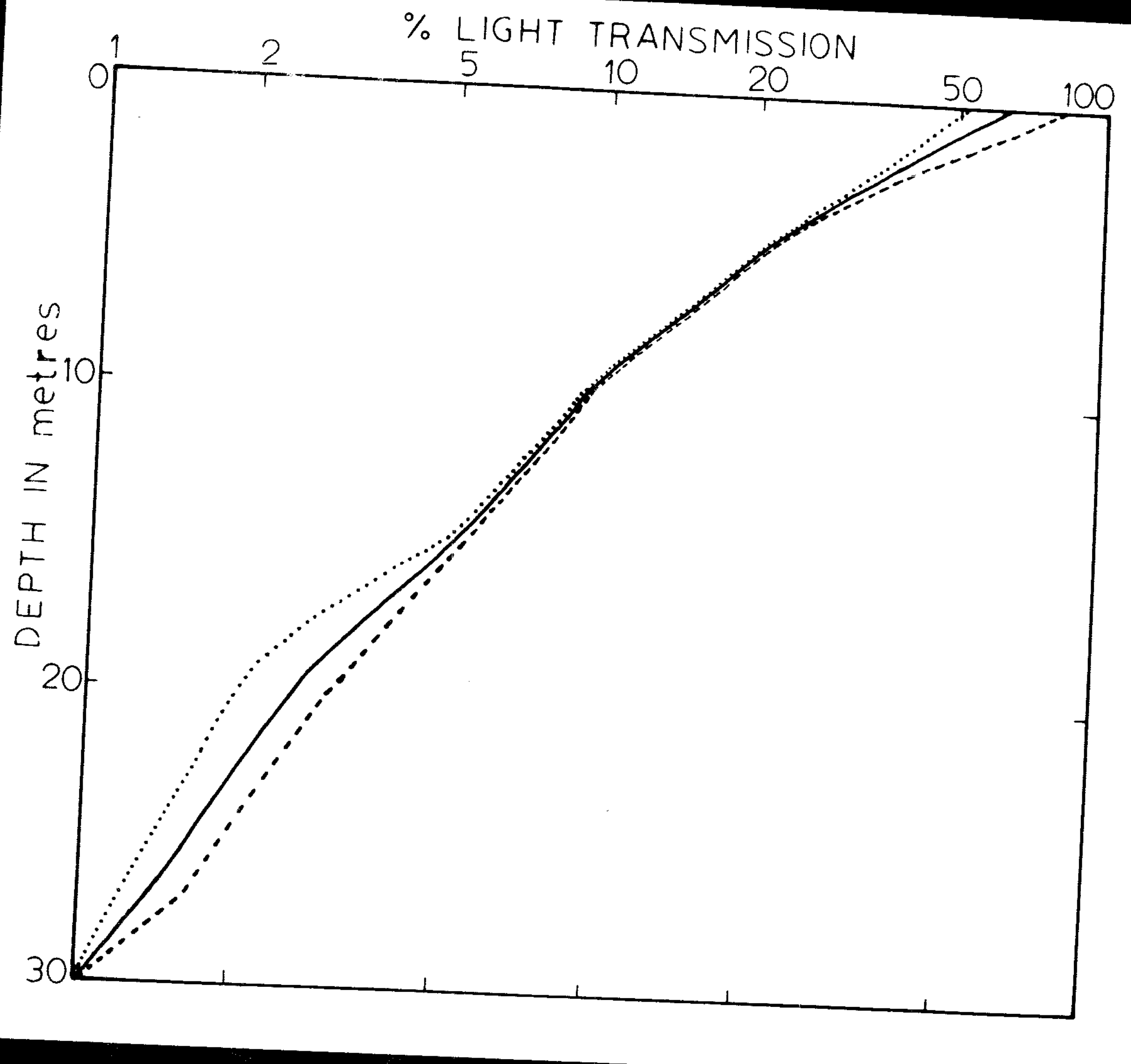

DEPTH IN metres
50
40
30
20
10
% LIGHT TRANSMISSION
1
2
5
10
20
50
100

Fig.16. Light penetration and depth of the eupho
zone at a station inside the continental
(60 m depth) in December. Bright day but
cloudy at the beginning of the measureme



16

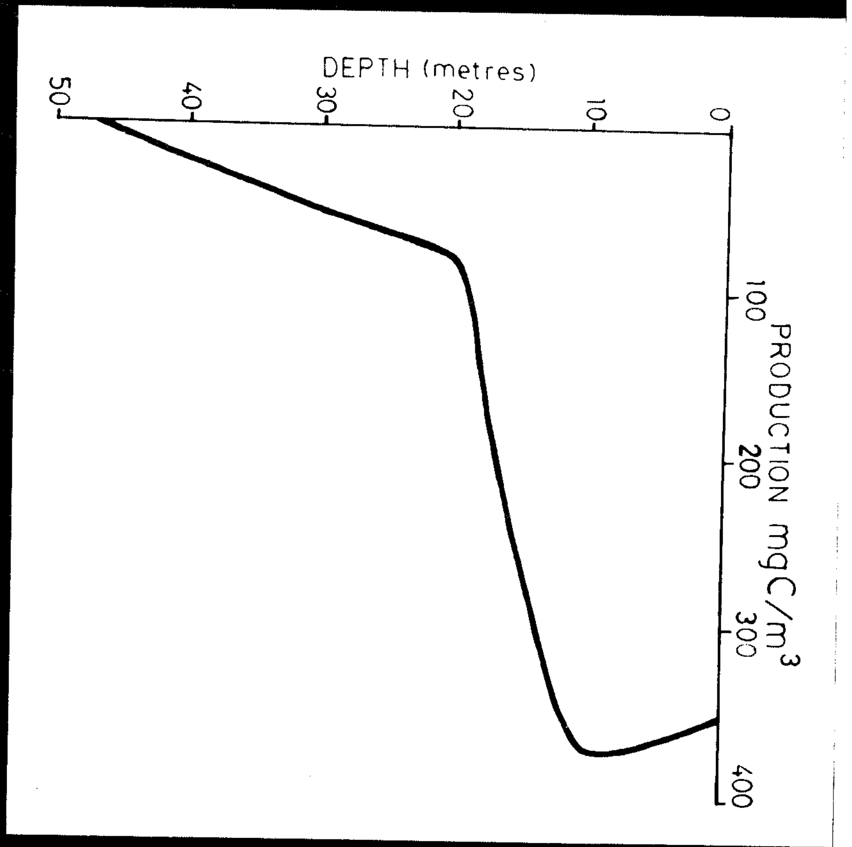
is only 5 metres in the near-shore waters and extends upto 30 metres in the oceanic waters outside the Laccadive Islands, indicating a euphotic zone of 90 metres. The transmission ratio at the depth of disappearance of the secchi disc was found to be normally about 17%. In clearer waters it is less - about 12%, and the relationship between extinction coefficient (k) and secchi disc depth (D) was $k = \frac{1.8}{D}$

The average extinction coefficient varies from 0.07 in the oceanic water to 0.32 in the coastal water. For a high extinction coefficient of 1.0, the compensation depth is 5 m, while a coefficient of 0.04 shows a high transparency which is symptomatic of low productivity (Ryther, 1963).

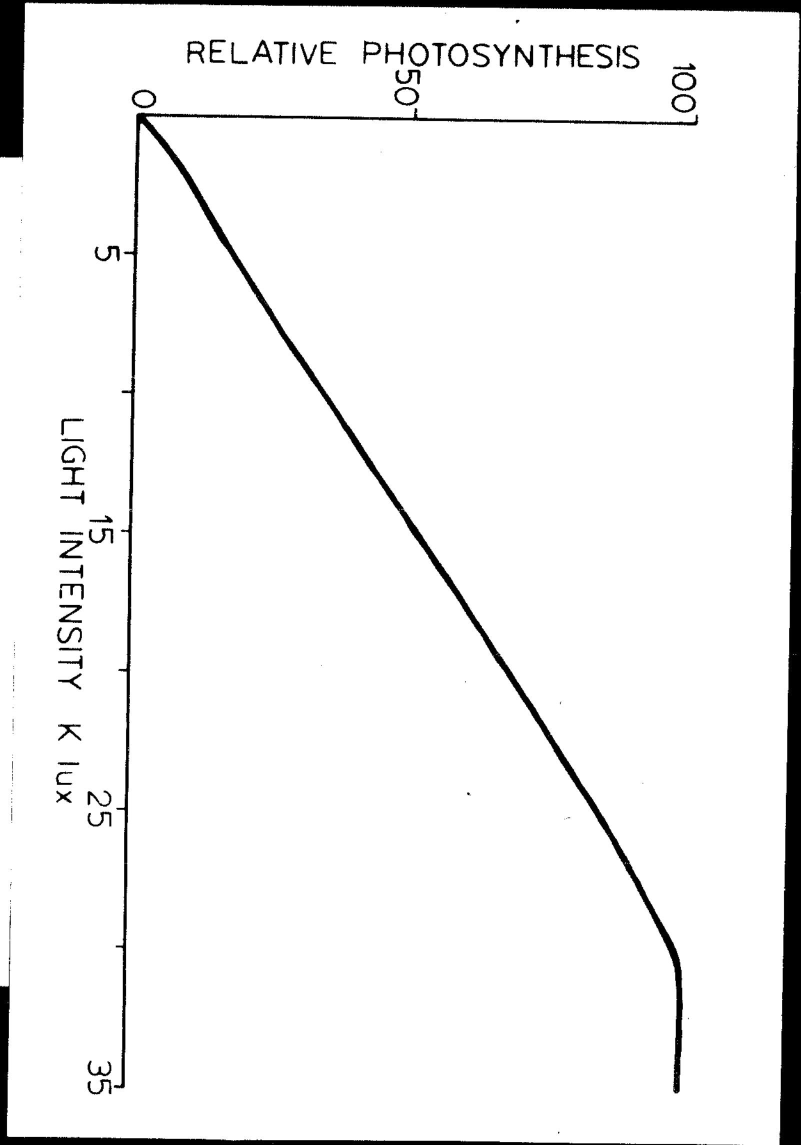
The rate of gross production as function of depth is given in Fig.18 for a station in the Gulf of Mannar near Tuticorin and the rate of photosynthesis as a function of the intensity of light in the surface water of the west coast is given in Fig.19. The maximum photosynthesis is reached at about 30,000 lux and the maximum rate of production is observed at 10 metres depth where the euphotic zone is 45 metres deep. The surface value was about 94%

Fig.18. Rate of gross production as a function of depth for a station in Gulf of Mannar off Tuticorin. The measurements are from an in situ experiment

Fig.19. Rate of photosynthesis as a function of light intensity with surface plankton from 08°17'N 76°45'E.


DEPTH (metres)
50
40
30
20
10
0
100
200
300
400
PRODUCTION mgC/m3

18


RELATIVE PHOTOSYNTHESIS
0
50
100
5
15
25
35
LIGHT INTENSITY K lux

19

of the maximum indicating only a slight inhibition. About 85% of the entire column production is within 20 metres. For the surface plankton of these waters the light saturation intensity continues until about 50,000 lux (Qasim *et al*.1969).

It may, however, be mentioned that recently Steemann Nielsen and Willemöes (1971) have pointed out that lux values, which several investigators have chosen to use in laboratory work with a definite light source, should now be abandoned. In field work it has no meaning with investigations on photosynthesis. In the absence of a quanta and energy meter the following conversion factors have been suggested:

1 klux daylight = 0.41 - 0.50 mWatt x cm^{-2} (Strickland 1958)

1 klux of fluorescent light = 0.72 mWatt x cm^{-2} (1.7 x 10^{15} quanta x cm^{-2} x $sec.^{-1}$ (Steemann Nielsen and Willemöes, 1971)

Nutrients

The variations in the nutrient concentration along the west coast of India from Cape Comorin to Karwar and in the Laccadive Sea were studied during 1967-1968. The reactive phosphate was estimated by the revised method of

Strickland and Parsons (1965) using a composite reagent of ascorbic acid, molybdic acid and trivalent antimony. The nitrate was estimated using the copper-hydrazine method and silicate by the metol-oxalic acid method of Strickland and Parsons (1960 and 1965).

The regional and seasonal variations in the nutrients in the upper layers show the same trend as in primary production. During the summer months preceding the monsoon, the nutrient concentrations near the coast as well as in the offshore areas are generally lower. The reactive phosphate varied from 0.20 to 0.38 µg at-P/l with very little gradient in the mixed layer. Near the bottom the values increased to 1.9 µg at-P/l. The nitrate values varied from 0.15 to 1 µg at-N/l and the silicate concentration ranged from 1.2 to 7.26 µg at-Si/l.

During the period of south-west monsoon (June to September) the nutrient concentration increases in the coastal regions. In the upper 20 metres between Cochin and Mangalore the level of phosphate concentration reaches 1.0 µg at-P/l. High values reaching 1.5 µg at-P/l are found off Mangalore where the maximum rate of primary production per unit volume has been recorded. The bottom values in the waters over the shelf reach up to 2.0 µg at.P/l. The whole continental shelf waters were rich in phosphate content during these months. A gradual increase from south to north was observed. As in the case of phosphate, nitrate and silicate values also were higher during this period. In the upper 50 metres near the coast, nitrate values ranged from 0.65 to 1.4 µg at.N/l, with the higher concentrations in the region north of Calicut. Silicate ranging from 2.5 to 7.5 µg at.Si/l were observed between Quilon and Mangalore.

During the post-monsoon period though there is a fall in the values of nutrients, the concentrations are high enough to maintain a moderately high rate of primary production. During the period of October to December the phosphate values ranged from 0.40 to 0.8 µg at.P/l in the southern regions between Cochin to Quilon. During the transition period of January-February the values were less.

In the mud bank area the nutrients were found to be in higher concentrations than in the other near-shore regions. 1.0 to 1.85 µg at.P/l observed during the summer months rises sharply to 2.5 to 3.75 µg at.P/l in a shallow area of 3.5 m depth. The nitrate values reach up to 2.50 to 3.25 µg at.N/l during the same period and so too the silicate reaching 24.0 to 57.0 µg at. Si/l in the mud bank area off Alleppey. During the post-monsoon and transition periods the silicate values fell to 4.6 - 11.7 µg at. Si/l when the values for the rest of the shelf was still less.

Thus the nutrient concentration in the waters over the shelf on the west coast of India follows a pronounced seasonal rytha reaching the maximum during the south-west monsoon months. This has been observed by Reddy and Sankaranarayanan (1968b) who inferred, from the vertical profiles of nutrients during the monsoon months, enrichment of coastal waters by the nutrients brought up from the subsurface levels.

A direct correlation between primary production and nutrient salts was observed by Kabanova (1964) during the 33rd cruise of VITIAZ in the Indian Ocean - low values of primary production coincided with the deficiency of nutrient salts. In the central part of the Arabian Sea and in the open part of the ocean nitrate was absent and in the Bay of Bengal and in the Andaman Sea phosphates were almost exhausted by phytoplankton.

Hence it may be concluded that in the Indian seas the seasonal variation and magnitude of primary production are influenced primarily by the availability of nutrients since the other important factors are never limiting. However, in very shallow regions where the bottom is always in contact with the overlying water, a low concentration of phosphate or other nutrients might lead to an erroneous inference as discussed in the next chapter. A low level of phosphate and the absence of a pronounced seasonal cycle is not symptomatic of a low rate of organic production as was observed in the Gulf of Mannar. As pointed out by Delsman (1939) a more rapid metabolism in the tropical seas would check an accumulation of nutrients.

Standing crop of phytoplankton

Monthly averages of phytoplankton cells, obtained by sedimenting and centrifuging surface samples from Station G1, varied from 360 cells/l in August to 583,000 cells /l in April. In the individual samples the variation was from 100 cells/l in the first week of August to 1,510,000 cells/l in the second week of April, the trend of variation being almost similar to that of primary production.

Koblentz-Mishke *et al.*(1970) remark that from the level of primary production in any particular region of the world ocean one can judge indirectly the relative variations in the number of phytoplankton cells. They found that despite the fact that the same production may correspond to the most varied counts of phytoplankton cells, there is a general correlation between the surface primary production and standing stock of phytoplankton. On the average, a higher level of primary production corresponds to a greater concentration of phytoplankton. The relation between cell numbers and primary production is given in Fig.20.

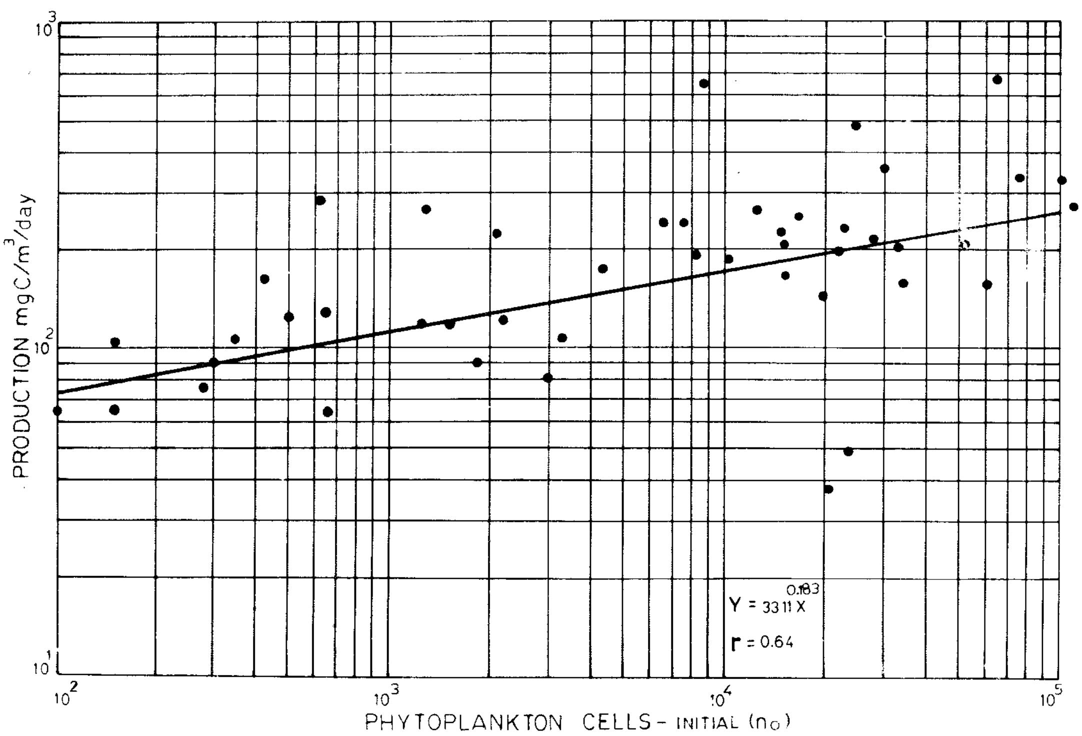
The measurements of chlorophyll concentration in the shallow regions do not seem to have much correlation with the standing crop. The earlier measurements in terms of Harvey Plant Pigment Units (HPPU) were converted to chlorophyll values by using the equivalent:

$$\text{mg chlorophyll} = (3 \pm 1 \times 10^{-4}) \times (\text{No.of HPPU's})$$

Accordingly the highest value of 23 mg/m^3 chlorophyll was found in April followed by 15 mg/m^3 in May and the lowest 2.7 mg/m^3 in October. The values obtained from calibration curves constructed out of chromatographically pure chlorophyll a were dissimilar to those obtained by the conversion method.

Recent measurements of chlorophyll a using a Unicam Spectrophotometer and by applying the revised equations of Parsons and Strickland (1963) showed chlorophyll a values ranging from 53 mg/m^3 to 69 mg/m^3 in April (Table 19). Higher values were generally recorded in the surface and near-surface samples excepting in one station where the maximum value was recorded at 10 m. The relationship between primary production and chlorophyll was not found to be significant. The correlation coefficient between log.primary

Fig.20. The relation between surface primary production ($mgC/m^3/day$) and standing stock of phytoplankton (number of cells/l) at station G1.



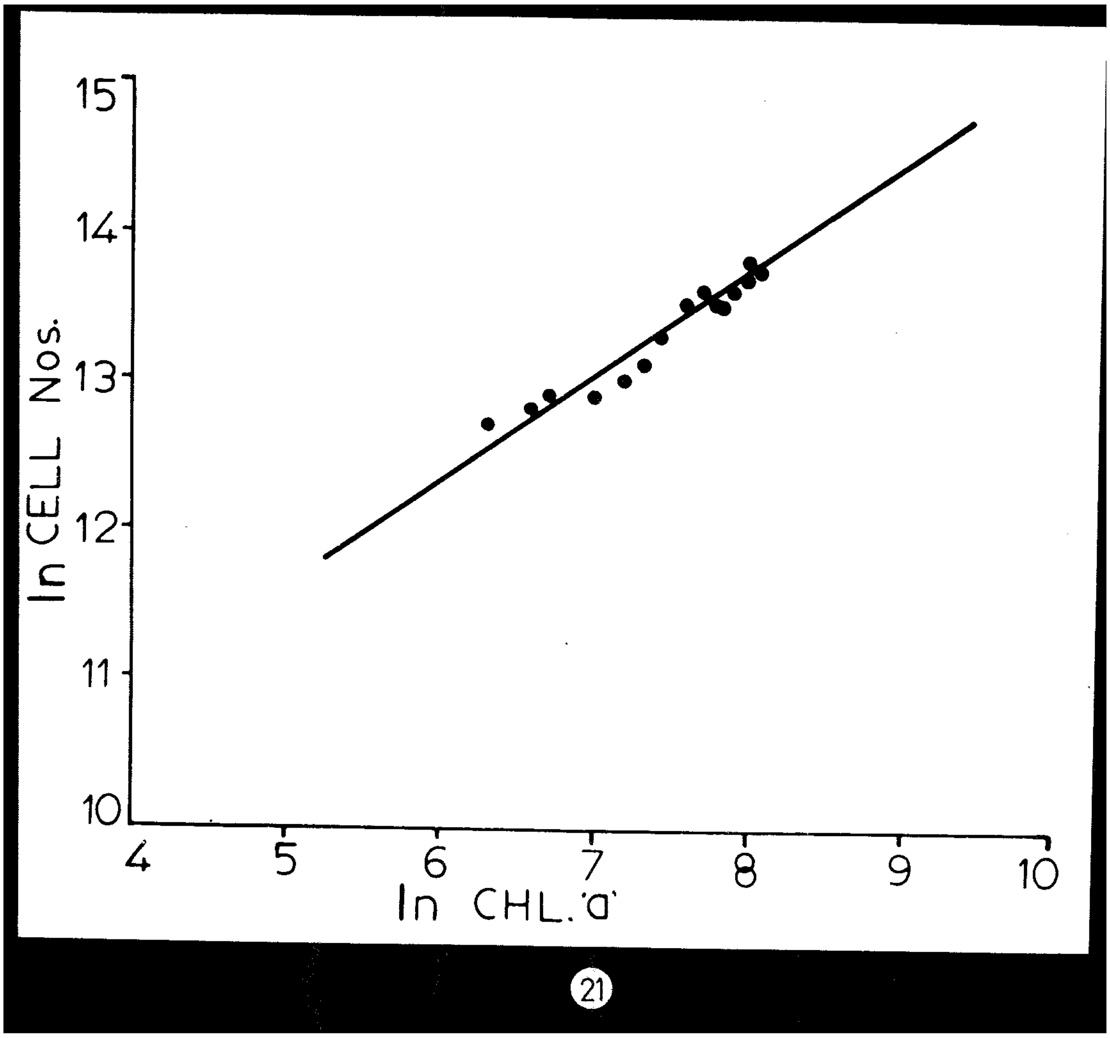
PRODUCTION mgC/m³/day
PHYTOPLANKTON CELLS - INITIAL (no)
Y = 33.11 X^0.183
r = 0.64

20

production ($mgC/m^3/day$) and log.chlorophyll a was found to be +0.44, -0.32 and +0.61 at surface, 1 metre and 5 metre depths respectively. The 'r' value between log. chlorophyll a and log.phytoplankton cells was also not significant being 0.14.

In the earlier analysis, when 43 sets of values on pigments and number of cells spread throughout the year were taken into consideration the correlation co-efficient was +0.542, which is highly significant. But for July to October it was -0.413. Hence it is felt that when the sea is choppy with high winds the pigment/chlorophyll values and cell numbers do not give the expected positive correlation. But a plot of chlorophyll a against cell numbers in a growing culture of *Tetraselmis* (Fig.21) shows a strong relationship, as should be expected. The field measurements especially in the inshore regions are considerably influenced by many extraneous factors which make the values of pigments unreliable. As Krey (1973) observes, chlorophyll values would at most indicate only the degree or level of primary production in an area due to the amount of error introduced by the unknown quantity of inactive or dead chlorophyll a present in the standing stock.

Fig.21. The relation between cell numbers and chloroph
a in a growing culture of *Tetraselmis gracilis*.



21
ln CELL Nos.
10
11
12
13
14
15
4
5
6
7
8
9
10
ln CHL.'a'

Table 19. <u>A few simultaneous measurements of primary production along with chlorophyll a and phytoplankton cell counts in the Gulf of Mannar (April 73).</u>

Depth (m)	Chlorophyll *a* (mg/m^3)	Primary production ($mgO/m^3/day$)	Total No. of photo-cells/1
1-4-1973: 08°55'N 78°25'E			
Forenoon			
0	26.70	218	526600
1	21.36	406	
5	--	226	
8	10.68	161	
Afternoon			
0	37.38	3912	
1	26.70	302	
5	32.04	232	
8	32.04	106	
[illegible]-4-1973: 08°54'N 78°22'E			
Forenoon			
0	42.72	148	124000
1	16.02	173	185600
5	37.38	302	113800
10	16.02	111	240000
15	10.68	3792	287000

(Contd. Table 19)

1	2	3	4
Afternoon			
0	32.04	125	805200
1	16-02	187	361400
5	21.36	334	619900
10	32.04	285	861000
15	21.36	73	503100
D	-	4020	
[illegible]-4-1973: 09°50'N 76°13'E			
0	16.02	141	716800
1	26.70	231	163400
5	48.06	195	488100
10	69.42	123	133400
15	37.38	65	124200
[illegible]-4-1973: 08°20'N 76°30'E			
0	5.34	38	385200
1	26.70	29	126000
5	16.02	26	294000
18	--	16	262000
30	10.68	31	264600

Standing crop of zooplankton

An analysis of the constituents of the zooplankters in the surface samples at station G1 reveal that broadly two groups could be recognised, one group of predominantly herbivores constituted by copepods, nauplii, larval stages of decapods, lamellibranchs, polychaetes and other forms like oikopleura. Obligatory carnivores like chaetognaths and hydromedusae form the second group. The quantitative distribution of these groups varied seasonally (Table 20), and based on their occurrence in the samples the following generalisations are possible: Total number of zooplankters constituted mainly by the herbivores were generally high during most part of the year. A marked decline was noted during June. A numerical augmentation was recorded during November. Carnivores were numerically less throughout the period of observation. Prasad (1954) while studying the distribution and fluctuations of planktonic larvae of Mandapam remarked that there is possibly a relation between the phytoplankton production and the larval maxima, the latter coinciding somewhat with periods of abundant phytoplankton.

Table 20. Mean monthly figures of zooplankters in 2 litre samples.

	Jy.	A	S	O	N	D	J	F	M	A	M	J
Predominantly herbivores	73	95	108	46	567	147	128	101	120	79	124	34
Carnivores	4	3	2	1	1	1	1	1	1	1	1	

Since phytoplankton is the food of the herbivorous zooplankton, in the long run, a large population can sustain only where the production of phytoplankton is high. An inverse relation between phytoplankton and zooplankton refers only to the momentary state of affairs, not the general relationship lasting over the whole year (Steemann Nielsen, 1958 c). The IIOE data on the distribution of zooplankton biomass (Prasad, 1969) show that the average annual distribution agree well with the general distribution and regional variation in primary production. The highly productive areas are found around the Somali and Arabian coasts and to a certain extent on the south-western coast of India. The low productivity zones occupy the central part of the Arabian sea. The southern hemisphere, especially south of 10°S latitude, exhibits a very low zooplankton biomass, whereas the regions south of the Indonesian Archipelago and the western coast of Australia show a higher density of zooplankton. The estimated biomass for the Indian Ocean comprising 51 million sq.km. of the Indian Ocean is 5.2×10^{8} tonnes as against 3.9×10^{9} tonnes of annual net production of carbon (Prasad, Banerji and Nair, 1970).

Discussion

To evaluate the primary production in natural habitat, the size of the gross production and the net production must be known. In the final reckoning with ^{14}C measurements some corrections and assumptions are inevitable to get either of the values. Thomas (1961) has summarised the four conditions which are to be met for the measurement of gross production by ^{14}C. Of these, the correction for the difference in the rate of assimilation of ^{14}C and ^{12}C has been ascertained at 6% (Steemann Nielsen, 1952 and 1955b).

The correction for non-photosynthetic uptake of ^{14}C is made by incubating a dark sample. This has been normally found to be about 1% in the surface samples and increasing towards the bottom. In certain rare instances bacterial fixation in the dark was found to be higher than photosynthetic fixation of ^{14}C (Table 19). Radhakrishna (1969) observed an average 42% dark fixation, with a range of 24 to 115% at the bottom of the euphotic zone, in the shelf regions of the west coast. Steemann Nielsen (1960b) has also observed values upto 30% for bottom samples. In view of such variability dark bottle corrections have been preferred over standard corrections.

The loss of extracellular products can vary from 1 to 20% as observed by Samuel, Shah and Fogg (1971) in these waters. Similarly the retention capacity of the filters differs according to the nature of the population. Hence the right selection of the filters, depending on the nature of the population, is also necessary in order to obtain accurate results. Millipore HA filters, which have been used for routine measurements, were found to have the maximum retention in the more productive inshore environments though they lose some radioactivity (3-13%) compared to Gelman filters having a pore-size of 0.30 μ, when the population is sparse. Göttingen membrane filters also were found to lose about 4 to 19% under the same conditions. But when the population is dense, the filters with smaller pore size (< 0.45 μ) lose the activity probably due to rupture of the cells.

The magnitude of correction for respiration that accompanies photosynthesis is rather uncertain. This correction is dependent upon the rate of respiration relative to that of gross photosynthesis. The crucial aspect of the correction for respiration is the P/R ratio, and the amount of intermixing of the two processes is of less importance (Thomas, 1961).

Steemann Nielsen and Hansen (1959) have described a method for measuring respiratory rate of autotrophic phytoplankton by means of ^{14}C technique. A curve showing the rate of net photosynthesis as a function of light intensity is obtained and by extrapolation the rate of respiration is deduced. Figs. 22 and 23 give rates of respiration, obtained by extrapolation, of surface samples from the Gulf of Mannar and Laccadive Sea. In both half the optimal rate was achieved at 10,000-11,000 lux. The rate of respiration obtained is rather high but not unusual—25% in the Gulf of Mannar and 30% in the oceanic sample from the Laccadive Sea. Qasim <u>et al</u>.(1969) observed respiration (day) as a percentage of gross varying from 20.6 to 45.5% in the Cochin backwater.

According to Steemann Nielsen and Hansen (1959) the rate of respiration in percentage of light-saturated photosynthesis is mostly 15% or less and in tropical surface

Fig.22. Rate of photosynthesis as a function of light intensity Surface plankton from the Gulf of Mannar. (Dashed line gives the corrected values

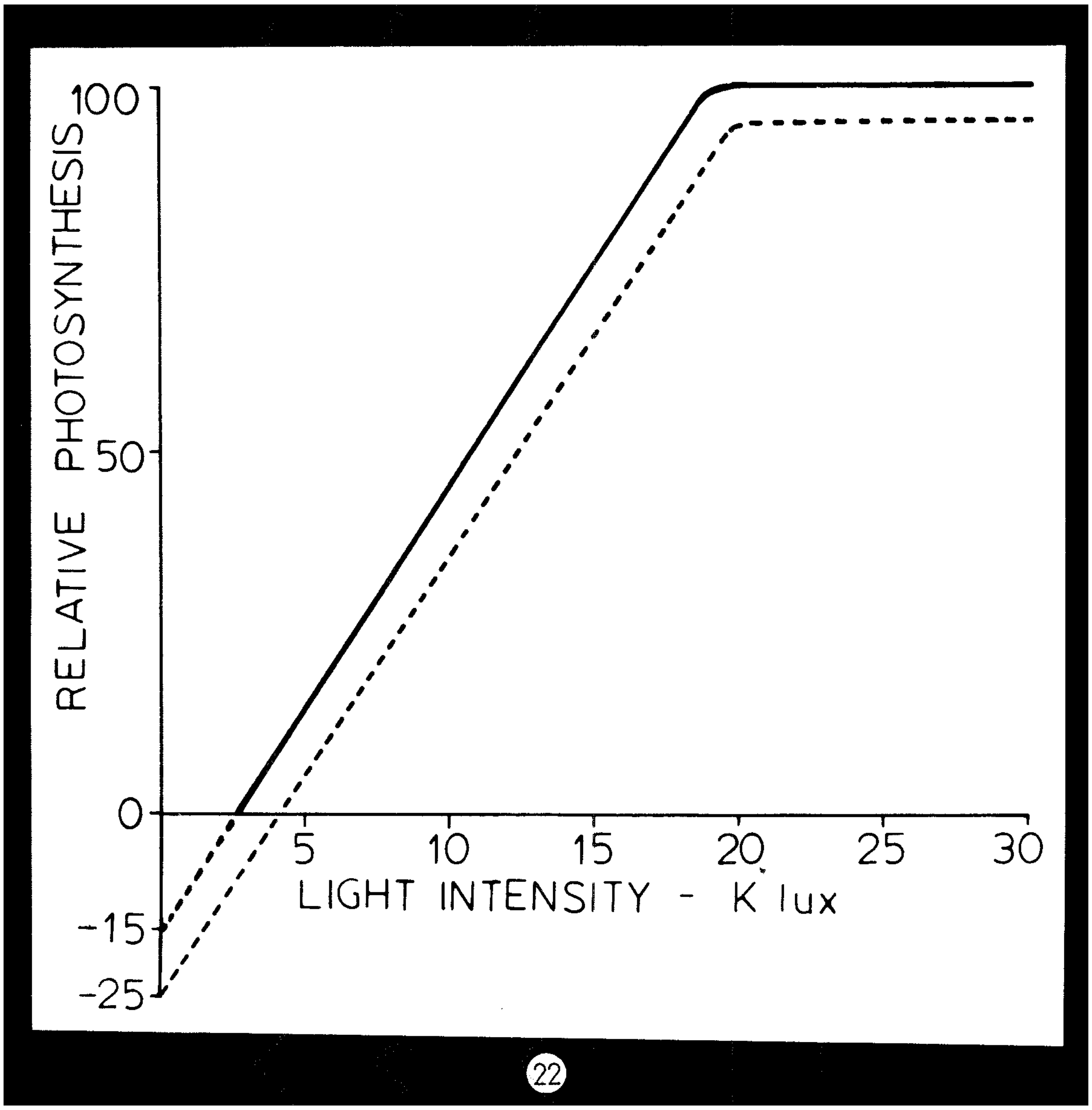
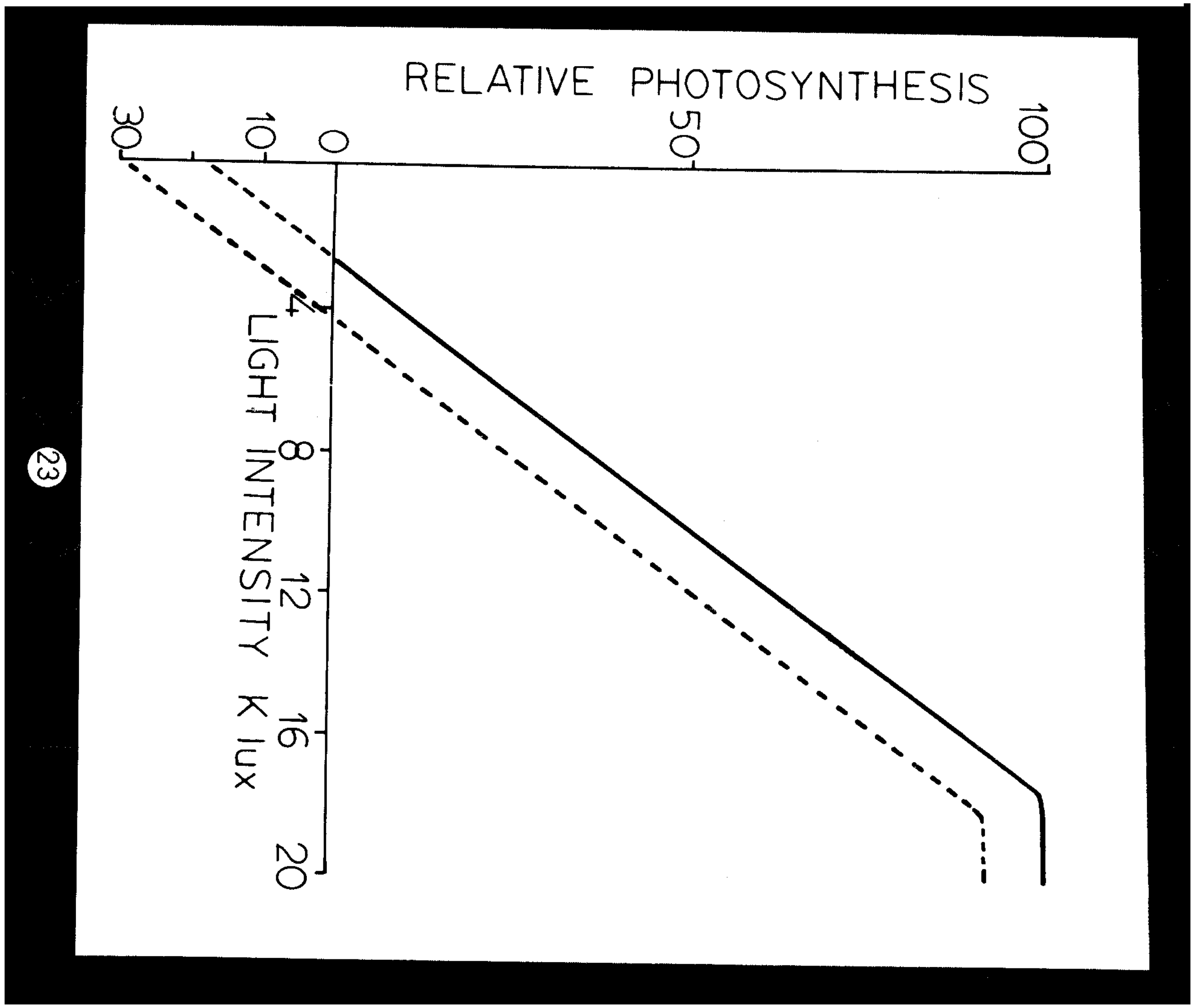

100
RELATIVE PHOTOSYNTHESIS
50
0
-15
-25
5
10
15
20
25
30
LIGHT INTENSITY - K lux
22

Fig.23. Rate of photosynthesis as a function of light intensity with Surface plankton from 11°19'N, 74°53'E (July). Dashed line represents corrected values.


23
RELATIVE PHOTOSYNTHESIS
100
50
0
10
30
LIGHT INTENSITY K lux
4
8
12
16
20

plankton generally below 10%. These authors also point out that the variation of the respiratory rate as a percentage of the maximum rate of photosynthesis is within a range of 5-25% and a rate of respiration higher than 30% of the optimum photosynthetic rate will, even in the upper half of the photic zone when integrated for all the algae found there, give rise to a decrease in the stock of algae. The higher rate observed by Qasim et al.(1969) is perhaps contributed by the zooplankters as the measurement is made from the oxygen decrease.

In the laboratory measurements with a culture of Tetraselmis a respiration rate of 37% was observed - Fig.24. (Fig.25 gives the respiration rate without the dark correction). Since the dark uptake was rather high it is presumed that the cells would have been N-deficient, as demonstrated by Steemann Nielsen and Al Kholy (1956). The influence of a respiratory rate differing from that arbitrarily chosen (10%) is insignificant if the rate of gross production only is wanted (Steemann Nielsen and Hansen, loc.cit.). Hence all the values are given as gross production. But ~~the~~ for the calculation of the net production per surface area per 24 hours the variation in the respiratory rate is more important. For want of a more accurate estimation

Fig.24. Rate of photosynthesis as a function of light intensity with a culture of Tetraselmis gracili[s]. The continuous line presents the values after making correction for dark uptake and the dashe[d] line corrected values for respiration.

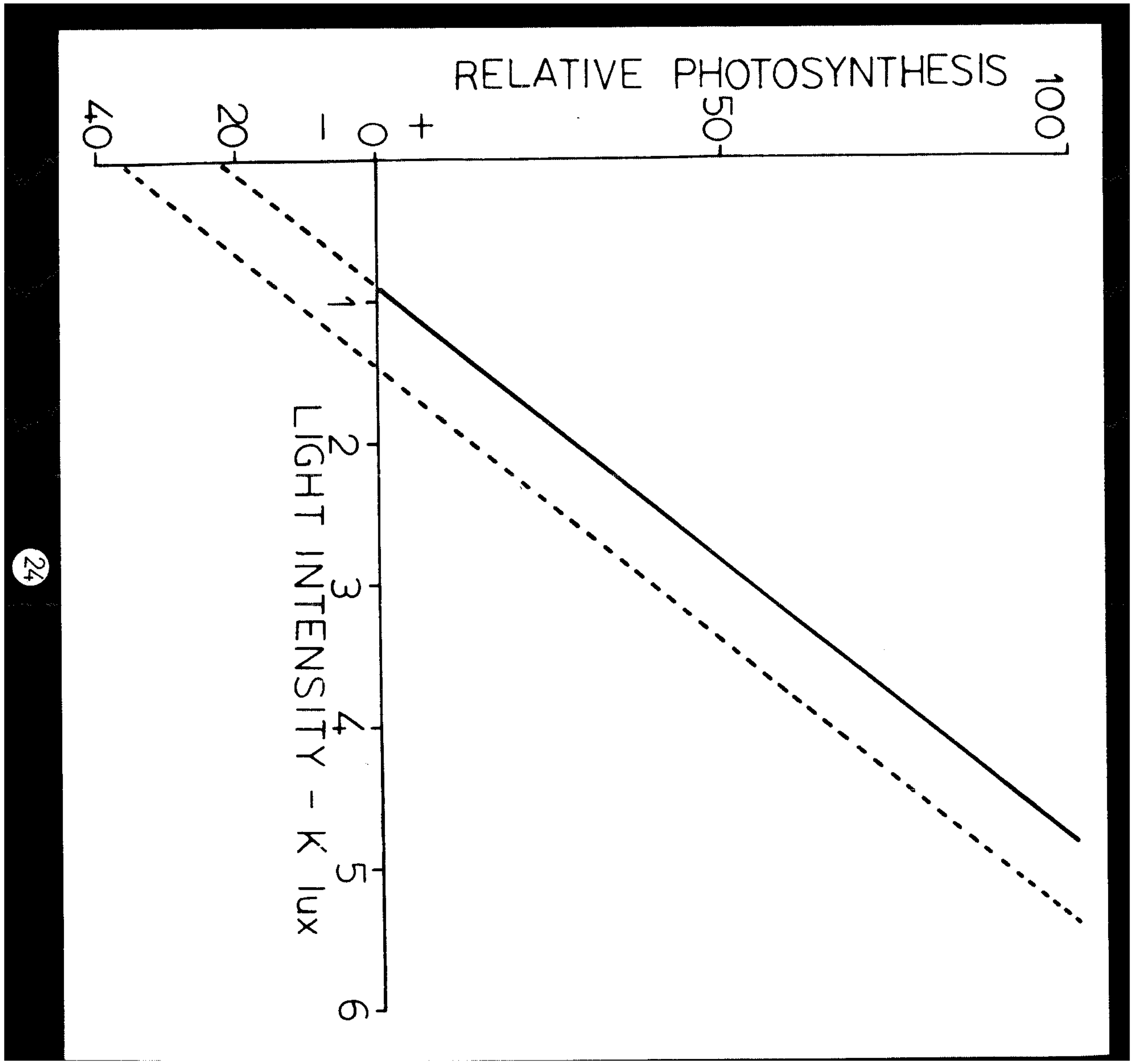

24
RELATIVE PHOTOSYNTHESIS
40
20
–
0
+
50
100
LIGHT INTENSITY - K lux
1
2
3
4
5
6

Fig.25. Same as in Fig.24 but without correction for dark uptake. The continuous line presents the observed values and the dashed line corrected values.

of respiration at different light depths during different light conditions, total net production for computation of potential yield has been taken as 60% of gross production.

The magnitude of primary production and its seasonal and regional variability in the Indian seas are influenced primarily by the availability of nutrients and the transparency of the water which affects depth of the euphotic zone since other parameters such as light or temperature are never limiting factors. It is also obvious that from the studies on the seasonal variation of the different phosphorus fractions. In the Gulf of Mannar it is not the instantaneous concentration of the essential elements that is important but the rate of replenishment (Cf.Ketchum, 1947). In the Gulf of Mannar and Palk Bay if the replinishment is caused by wind and wave action, on the west coast it is by the processes associated with upwelling of deep waters and ocean currents.

The bottom mud especially on the west coast is a rich store house of nutrients which are released into the waters during the south-west monsoon generally and during periods of high winds when a mixing up of the layers occurs. Seshappa (1953) and Seshappa and Jayaraman (1956) investigated the bottom muds of an inshore area on the west coast.

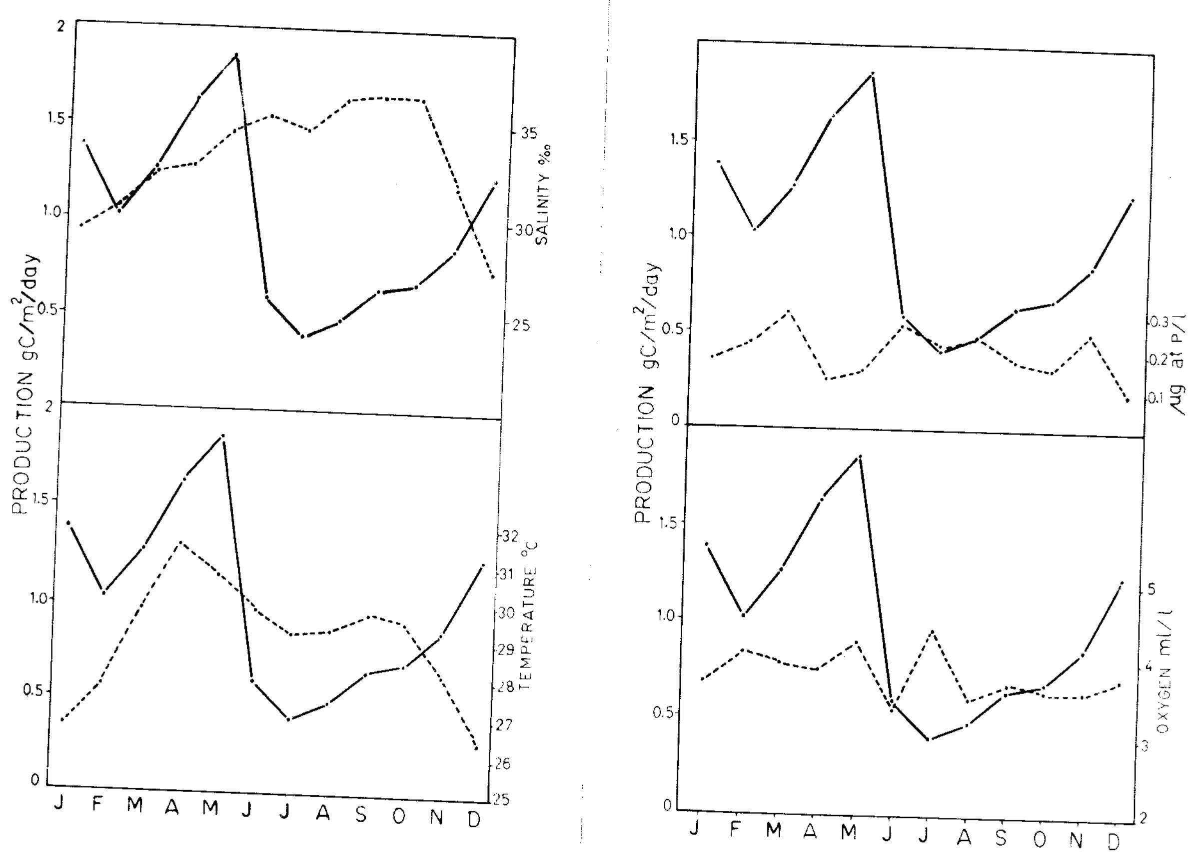
They found that the values for interstitial phosphate were higher than corresponding values for inorganic phosphate in the overlying water during the pre-monsoon months and that the mud retains relatively large quantities of phosphate and other nutrients. It was also observed that the mud is of laterite origin and an analysis of the sample of laterite by them revealed high adsorbed phosphate.

Another cause for the increase of phosphate during the south-west monsoon months is attributed to the death and decay of bottom fauna at the commencement of the season. It is therefore likely that during the south-west monsoon season the phosphate in the mud is also released by high winds apart from the supply generated by the process of upwelling. These may explain the high concentration of phosphate in the waters of the west coast during the bloom of phytoplankton unlike in the Gulf of Mannar. Obviously there is more phosphate in the inshore waters of the west coast than is required for the growth of phytoplankton (Subrahmanyan, 1959). Later with the onset of calmer conditions the death and decay of the plankton that sink to the bottom liberate phosphates in the bottom sediments which become available again during the next monsoon. This cyclical seasonal exchange of phosphorus between the sediment and water has been confirmed for the west coast by Seshappa (1953) and Seshappa and Jayaraman (1956).

The phenomenon of upwelling on the west coast has also a pronounced effect on the replenishment of nutrients and thereby on primary production. The maximum effect of upwelling can be observed in the surface layers only when the deepest possible water enters the surface layers and also after a period of its presence. The time lag between replenishment and phytoplankton production is reflected in the spatial and temporal variation in the flowering of the diatoms. On the Trivandrum coast (about 8°30'N) diatoms gradually increase from January reaching the maximum in May (Menon, 1945; Nair, 1958). At Calicut the peak of the bloom, judged by the cell numbers is attained either in June or July when the monsoon is most active (Subrahmanyan, 1959). In the shallow areas of the Gulf of Mannar and Palk Bay the variation is not so much as the waters are mixed to the bottom and the phytoplankters have access to the nutrients in the water column and also what is generated from the bottom.

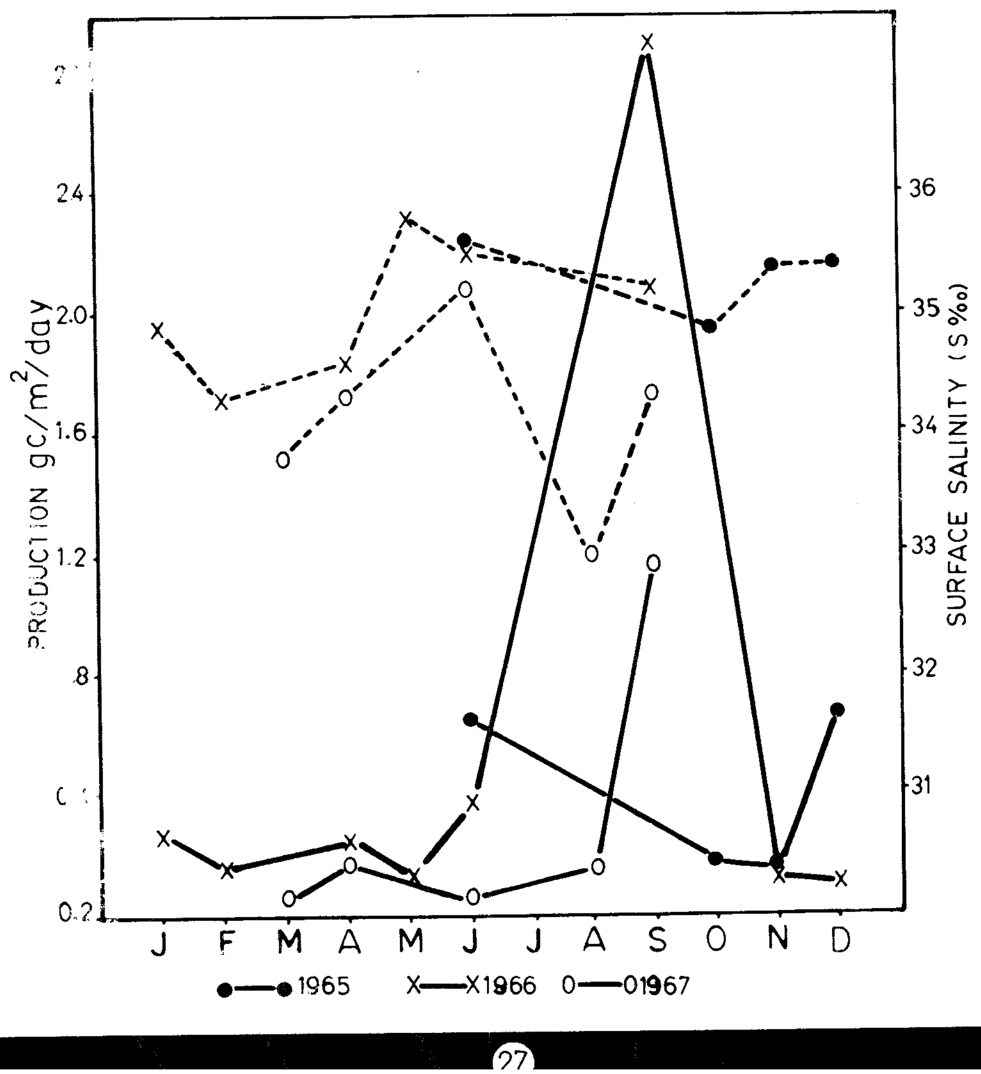
It may be seen from Figs. 26 and 27 that seasonal variation in salinity is not of direct importance on the rate of organic production though in a tropical estuary near Cochin many phytoplankters were found to bloom at exceptionally low salinities. Qasim, Bhattathiri and Devassey (1972) who studied the behaviour of certain phytoplankters isolated from the estuary remark that

Fig.26. The seasonal trend in primary production in the Gulf of Mannar plotted against the common hydrographic properties. The values are only for the reference station during one year of observation. .———. Primary Production.



PRODUCTION gC/m²/day
SALINITY ‰
TEMPERATURE °C
OXYGEN ml/l
/ug at P/l
J F M A M J J A S O N D

Fig.27. The rate of primary production ($gC/m^2/day$) for three years plotted against the respectiv salinity (‰) values on the west coast.


PRODUCTION gC/m²/day
SURFACE SALINITY (S‰)
0.2
.8
1.2
1.6
2.0
2.4
31
32
33
34
35
36
J F M A M J J A S O N D
1965
X—X 1966
0—0 1967

the adaptation for maximum photosynthesis in response to low salinity is to ensure their peak production during a time when high concentration of nutrients are available in the environment.

The temperature also though does not exhibit any direct relation (Fig.26) has an indirect influence on the rate of primary production through regeneration of nutrient salts. According to Steemann Nielsen and Aabye Jensen (1957) the reason for the high rate of primary production in the shallow regions of the tropics is that the high temperature at the top of the bottom sediments causes a high regeneration of the nutrient salts which by diffusion and other mechanisms are transferred into the water layers above that brings forth an immediate effect on the production by phytoplankton.

In the offshore waters of the west coast on the other hand, it is the inter-relationship of the euphotic zone and mixed layer that determine the rate of production. As mentioned before, the depth of the mixed layer during pre-monsoon period is about 60 m which becomes less than 20 m during the monsoon period. During the post-monsoon period it deepens to 40 m. The euphotic zone in these regions is never more than 50-60 m. In the pre-monsoon period as there is no further admixture of nutrient-rich water the rate of production is maintained at a lower level till the commencement of upwelling. During the post-monsoon period when the mixed layer deepens the nutrients have not been depleted and hence moderately high production continues during this period.

Steele (1956) associates differences in production for the Fladen Ground in the northern North Sea as a whole from year to year, as well as differences between one area and another, chiefly to variations in mixing which act as a brake on production. Ketchum et al. (1958) have also emphasised the great importance of vertical mixing and of regeneration in supplying nutrients for primary production. The lower rate of primary production during the pre-monsoon and the higher rates during monsoon and post-monsoon periods as well as the lower values observed seaward are thus accounted directly to the availability of nutrients.

The magnitude of annual primary production (gross) obtained in the present study along with some values from different regions and ecosystems are presented in Table 21 for comparison.

Table 21. Annual primary production in certain marine and estuarine environments

Locality	Production gC/m²/year	Reference
Barents Sea ..	170-330	Kreps and Verjbinskaya, 1932
English Channel ..	60-98	Cooper, 1933
Georges Bank ..	309	Riley, Stommel and Bumpus, 1949
North Sea ..	57-82	Steele, 1956
Long Island Sound ..	470	Riley, 1956
Off Hawaii (open ocean)..	21	Doty and Oguri, 1956
Off Hawaii (inshore) ..	123	-do-
Turtle grass bed (Florida)	4,650	Odum, 1956
Hawaiian coral reef ..	2,900	Kohn and Helfrich, 1957
Shelf waters off New York:		
Shallow coastal region	160	Ryther and Yentsch, 1958
Continental slope	100	Ryther and Yentsch, 1958
North Central Sargasso Sea	78	-do-
Temperate Oceans	100-150	Strickland, 1965
Equator ..	110-146	-do-
Barren tropical oceans ..	50	-do-
Cochin Backwater (India)	281	Qasim *et al*. 1968
East coast (Continental shelf)	230	Nair *et al*., 1968
West coast of India (within 50 m depth)	453	Present study
Gulf of Mannar (inshore Average 6 m depth)	400	Present study
Palk Bay	561	Present study

PHOSPHORUS FRACTIONS IN GULF OF MANNAR AND THEIR RELATION TO PRIMARY PRODUCTION

Phosphorus exists in sea water as dissolved inorganic phosphate, dissolved organic phosphorus compounds and particulate phosphorus as represented by plankton and detritus, as also by insoluble and adsorbed phosphates in suspension. Inorganic phosphate and total phosphorus determinations on a sea water sample before and after filtration will allow the estimation of the different fractions of phosphorus. Particulate phosphorus is found as the difference between the estimations of the unfiltered and filtered samples and the dissolved organic phosphate as the difference between the values for the total filtered sample and for the inorganic fractions.

The work of Redfield et al. (1937) in the Gulf of Maine and of Armstrong and Harvey (1950) in the English Channel provide the basic information of the three fractions of phosphorus-containing materials in the sea.

In India investigations on the seasonal variations in the phosphate content of the coastal waters have been conducted by Jayaraman (1951) and Ramamurty (1953) at Madras, Jayaraman (1954) in Gulf of Mannar and Palk Bay, George (1953), Rao (1957) and Subrahmanyan (1959) at Calicut and by Reddy and Sankaranarayanan (1968b) for the shelf waters of the Arabian Sea. Besides, Seshappa and Jayaraman (1956) have studied the phosphates in the mud banks at Calicut and Qasim *et al*. (1969) in the Cochin backwaters. Extensive phosphate determinations over the Arabian Sea have been carried out during the IIOE recently; even prior to this, DANA, DISCOVERY and GALATHEA Expeditions had measured the distribution of phosphates in the Indian Ocean (Clowes, 1938; Steemann Nielsen and Aabye Jensen, 1957). However, the pattern of the relative changes in the three fractions has not yet been studied.

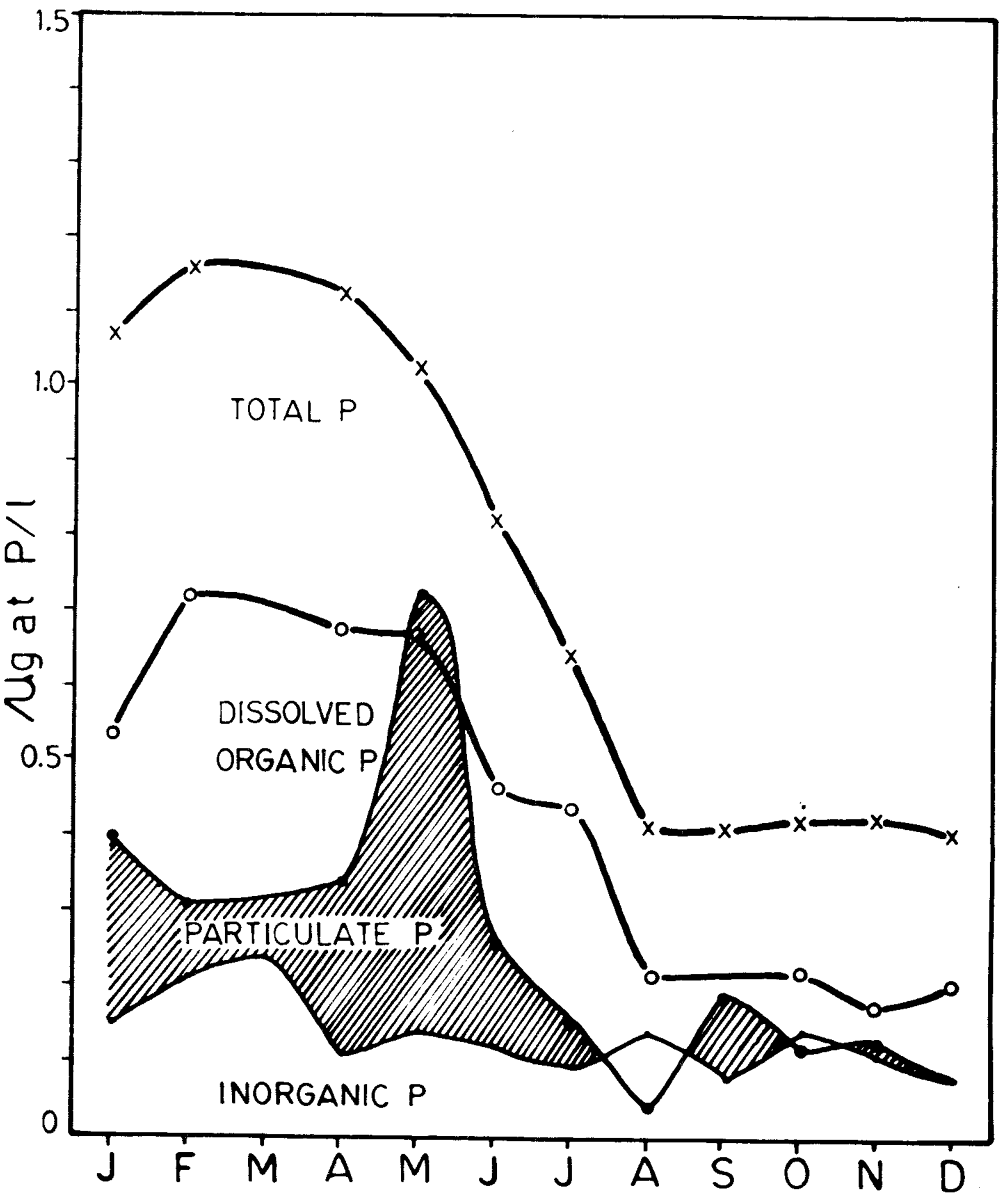
As the greatest change in the three fractions of phosphorus takes place in the surface waters, samples collected from the surface in Gulf of Mannar were analysed as part of the primary production studies. Duplicate samples of 'light' and 'dark' bottles were also analysed after a twenty four hour period of *in situ* incubation. The method for the determination of inorganic phosphate was that of Robinson and Thompson (1948) and for total phosphorus perchloric acid digestion method of Hansen and Robinson (1953). The optical density was measured by a Hillger and Watts Spekker Absorptiometer with a red filter and the values were derived from calibration curves constructed with known standards. The values of the various fractions in the initial samples are given in Table 22.

The inorganic phosphate values were relatively low in Gulf of Mannar and did not show much seasonal variation. The monthly average values varied from 0.08 to 0.29 µg.at.P/1. The earlier investigations of Jayaraman (1954) also showed a similar pattern and magnitude. The peak value was seen in March with minor peaks in May, August and October. The total phosphorus, dissolved organic phosphate and particulate phosphorus, on the other hand, showed well-marked seasonal variation (Fig.18), though the magnitude of all the fractions was still of a lower order compared to that of the waters in the higher latitudes.

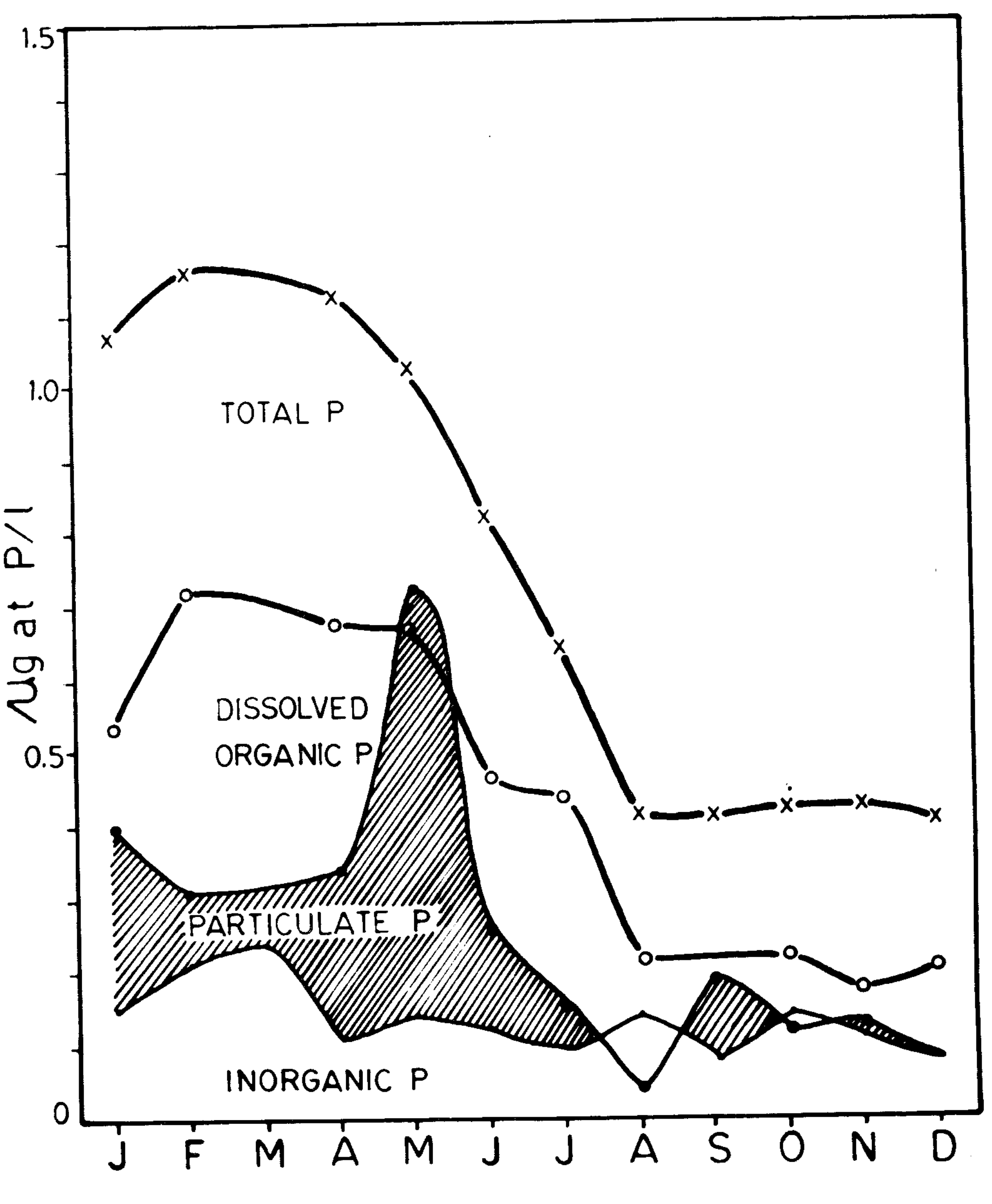
The total phosphorus remained over 1 µg.at.P/1 from January to May, between 0.5 and 1.0 µg at.P/1 from May to July and at about 0.4 µg at.P/1 for the rest of the year.

The same trend has been observed for the dissolved organic phosphate also which showed values >0.5 µg.at.P/1 between January and May. From August to December it remained at the lowest level of 0.2 µg.at.P/1. The bulk of the phosphorus content in the Gulf waters thus appears to be in dissolved organic form, the percentage distribution being over 50% on the average. It has been found to exceed 70% at times and only in one instance it had been reduced to less than 20%. Rao (1957) has found that organic phosphorus formed 63-91.5% of the total phosphorus except in June when the south-west monsoon caused stirring up of sediment, which resulted in relatively less organic phosphate in solution.

Fig.28. Seasonal changes in the different phosphorus fractions in Gulf of Mannar (initial samples - surface)


1.5
1.0
0.5
0
/ug at P/l
TOTAL P
DISSOLVED
ORGANIC P
PARTICULATE P
INORGANIC P
J
F
M
A
M
J
J
A
S
O
N
D

28


1.5
1.0
0.5
0
Λug at P/l
TOTAL P
DISSOLVED
ORGANIC P
PARTICULATE P
INORGANIC P
J F M A M J J A S O N D

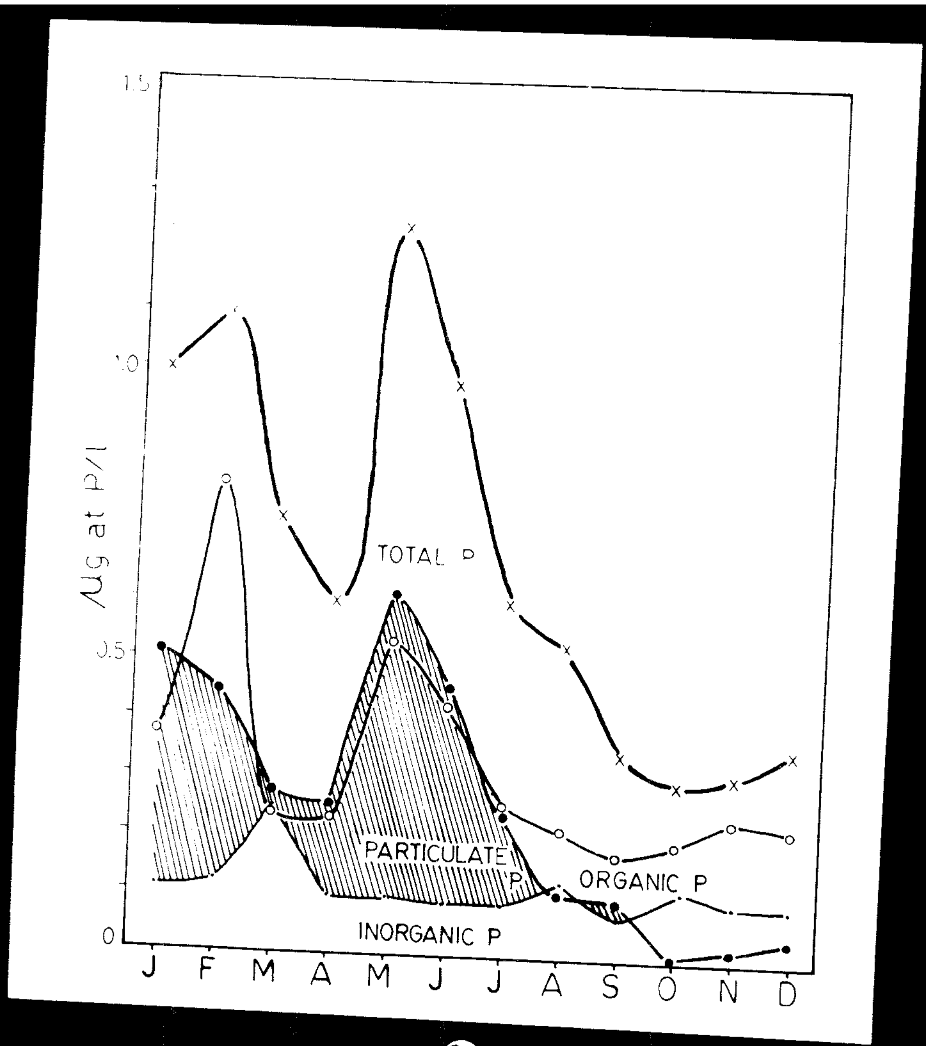
28

The particulate phosphorus, the dominant fraction next to dissolved organic P, was available in varying proportions from January to July and September to November with the maximum values in May (ca. 0.85 μg.at.P/1). In fact, only during May the percentage contribution of particulate phosphorus as well as its magnitude exceeded that of the organic phosphorus fraction. This is presumably because of the high phytoplankton production (300-400 mg C/m^3/day in the surface waters) during this period. Because of the nature of sampling it is unlikely that zooplankton organisms would have contributed to this fraction. So it is likely that the particulate phosphorus values obtained in this study were predominantly contributed by the phytoplankton and to a lesser extent possibly by detritus.

The inorganic fraction remains for the most part of the year at a low level of 12-15%. In March during the peak period it formed about 36%. The highest percentage contribution, however, was in August when it even formed 48% of the total at a time. The particulate phosphorus on that occasion was nil.

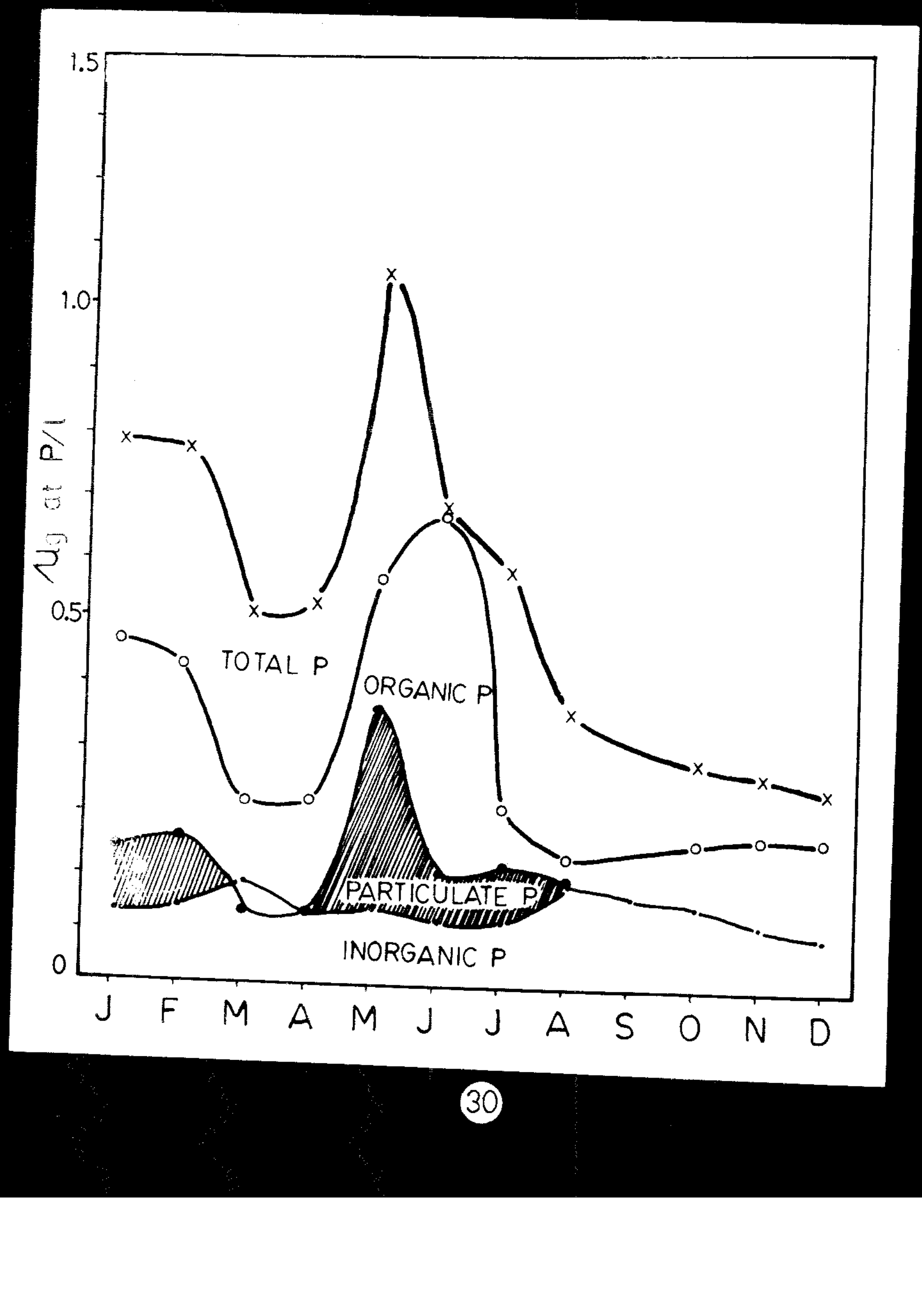
The trend for the three fractions is seen to persist in the 'light' and 'dark' bottles at the end of the experimental period of twenty four hours (Figs. 29 and 30) when oxygen measurement was taken to estimate the gross primary production, except in March-April which is the period of

Fig.29. Seasonal changes in the different phosphorus fractions in samples from Gulf of Mannar after incubation in light bottles for 24 hours *in situ*.


1.5
1.0
0.5
0
Ug at P/l
TOTAL P
PARTICULATE P
ORGANIC P
INORGANIC P
J F M A M J J A S O N D

29

Fig.30. Seasonal changes in the different phosphorus fraction in samples from Gulf of Mannar after incubation in dark bottles for 24 hours *in situ*.


1.5
1.0
0.5
0
µg at P/l
TOTAL P
ORGANIC P
PARTICULATE P
INORGANIC P
J F M A M J J A S O N D

30

zooplankton peak and excessive grazing of the phytoplankton. The 'dent' observed in the particulate fraction at the time could probably be the effect of grazing of the enclosed population. At all other times a consistent increase of phytoplankton cells was observed in the light bottles which accounts for the increase in the particulate fraction as compared to that of the dissolved organic fraction.

While discussing the comparatively lower level of phosphate in Gulf of Mannar combined with the absence of marked seasonal cycles, Jayaraman (1954) had speculated whether this indicated a low level of organic production too in these waters. However, he had also stressed the contention of Delsman (1939) that probably the more rapid metabolism in the tropical seas would check such an accumulation of nutrients as usually occurs in most northern waters during thewinter. A high rate of photosynthesis in the surface water all through the year requires a considerable amount of nutrients. As shown by Ketchum (1947), it is the replenishment and not the instantaneous concentration which determines the fertility of an aquatic environment.

The regeneration of phosphate could be measured indirectly i.e. roughly 1 mgP is assimilated for every 40 - 50 mgC (Steemann Nielsen and Aabye Jensen, 1957). The values of organic production at this station for the period varied between 124 mgC/m^3/day in July to 388 mgC/m^3/day in April with an annual mean of 202 mgC/m^3/day (Prasad and Nair, 1963). So the daily phosphate assimilation may be assumed to be about 4 mg/m^3/day (0.13 μg.at.P/1) which is about the average quantity available in solution. The inorganic phosphate in solution at any moment in a water mass may represent from 1 to 500 per cent of the amount taking part in the daily metabolism (Steemann Nielsen, 1951).

It may thus be seen that the amount of phosphate assimilation in the shallow waters of Gulf of Mannar is almost equal to the instantaneous concentration of the inorganic phosphate. As the water masses are without stratification throughout the year and are in constant contact with the bottom, the regeneration of phosphate taking place at the bottom is constantly utilised by the phytoplankton at almost the same rate. The speed of regeneration from the shallow bottom seems to be high enough to maintain the phosphate at a constant level.

Table 22. Seasonal distribution of the three phosphorus fractions at the surface in the Gulf of Mannar during the different months

riod	Total P µg.at./l.	Inorganic P µg.at./l	I.P. %	Organic P µg.at./l	O.P. %	Parti-culate P.µg.at./l	P.P. %
nary	0.63	0.12	19.1	0.36	57.1	0.15	23.8
	0.81	0.10	12.3	0.51	63.0	0.20	24.7
	1.76	0.22	12.5	0.69	39.2	0.85	48.3
ruary	1.06	0.10	9.4	0.46	43.4	0.50	47.2
	1.71	0.14	8.2	1.09	63.7	0.48	28.1
	0.96	0.28	29.2	0.59	61.4	0.09	9.4
	0.94	0.11	11.7	0.72	76.6	0.11	11.7
ch	0.63	0.24	38.1	0.32	50.8	0.07	11.1
il	0.87	0.10	11.5	0.65	74.7	0.12	13.8
	0.63	0.11	17.4	0.49	77.7	0.03	4.9
	1.88	0.13	7.0	0.90	47.8	0.85	45.2
	1.15	0.18	15.7	0.38	33.0	0.59	51.3
	2.09	0.18	8.6	1.07	51.2	0.84	40.2
	0.59	0.09	15.3	0.42	71.3	0.08	13.4
	1.13	0.13	11.5	0.49	43.4	0.51	45.1
	0.79	0.15	19.0	0.60	76.0	0.04	5.0
	0.78	0.09	11.5	0.32	41.1	0.37	47.4
	0.92	0.05	5.4	0.57	62.0	0.30	32.6
	0.62	0.14	22.6	0.42	67.7	0.06	9.7
st	0.56	0.15	26.8	0.41	73.2	-	-
	0.51	0.14	27.4	0.25	49.1	0.12	23.5
	0.23	0.11	47.8	0.12	52.2	-	-
	0.35	0.14	40.0	0.17	48.6	0.04	11.4
mber	0.41	0.08	19.5	0.14	34.2	0.19	46.3
ber	0.56	0.12	21.4	0.22	39.3	0.22	39.3
	0.37	0.12	32.4	0.23	62.2	0.02	5.4
mber	0.34	0.11	32.4	0.19	55.9	0.04	11.7
	0.31	0.11	35.5	0.06	19.3	0.14	45.2
	0.56	0.11	19.6	0.26	46.4	0.19	34.0
mber	0.34	0.08	23.5	0.20	58.8	0.06	17.7
	0.72	0.15	20.8	0.41	57.0	0.16	22.2

THE TOTAL ORGANIC NITROGEN IN PARTICULATE MATTER AS AN INDEX OF PRIMARY PRODUCTION IN THE GULF OF MANNAR

The circulation of nitrogen in the sea is based on the quantitative relationships involved in the various steps of the nitrogen cycle viz., living organisms, dead organisms, ammonia, nitrite, nitrate, living organisms. Among these the soluble substances have received considerable attention and a lot of information has been accumulated concerning their quantitative occurrence in various seas, seasonal fluctuations and their influence on the plankton production.

The determination of protein from total cell nitrogen of phytoplankton by multiplication with a conversion factor of 6.25 is a standard practice and is considered satisfactory for most field work (Strickland, 1965). However the nitrogen present in the plankton and its seasonal variation has not received much attention. Though attempts have been made to calculate nitrogen occurring in the organisms from nitrate data it has not met with success. The movements of the water masses and the turnover of the organisms make it impossible to determine the amount of nitrogen present in the particulate matter in any part of the sea at a given moment from nitrate data taken at intervals of several weeks or months. Hence a micro-technique for the determination of organic nitrogen in sea water and plankton was used by Von Brand (1935). This study involves the determination of protein from kjeldahl nitrogen in combination with a sedimentation technique normally used for the counting of phytoplankton in order to assess how far these values represent the standing crop.

One litre of water collected at the same time along with the samples for oxygen and also samples from light and dark bottles after twenty four hours were treated with 40 ml of 40% of Na_2CO_3 solution. They were shaken well and after half an hour filtered through fluted filter paper. The precipitates were then washed with several changes of distilled water. Afterwards the precipitates were washed into centrifuge tubes and centrifuged at 3000 r.p.m. The precipitates were further centrifuged with two or three changes of distilled water and were then transferred to kjeldahl flasks. 2 ml of concentrated sulphuric acid and a pinch of K_2SO_4 - $CuSO_4$ mixture were then added and then digested. After cooling it was taken up with distilled water and ammonia estimated in a microkjeldahl in the presence of excess NaOH. Blanks were also run along with all the analyses and corrections made. Altogether 47 analyses were conducted spread over an eighteen-month period.

The values of nitrogen were converted into protein by multiplying with the factor 6.25.

Table 23 gives the mean values obtained for each month with the corresponding values for primary production.

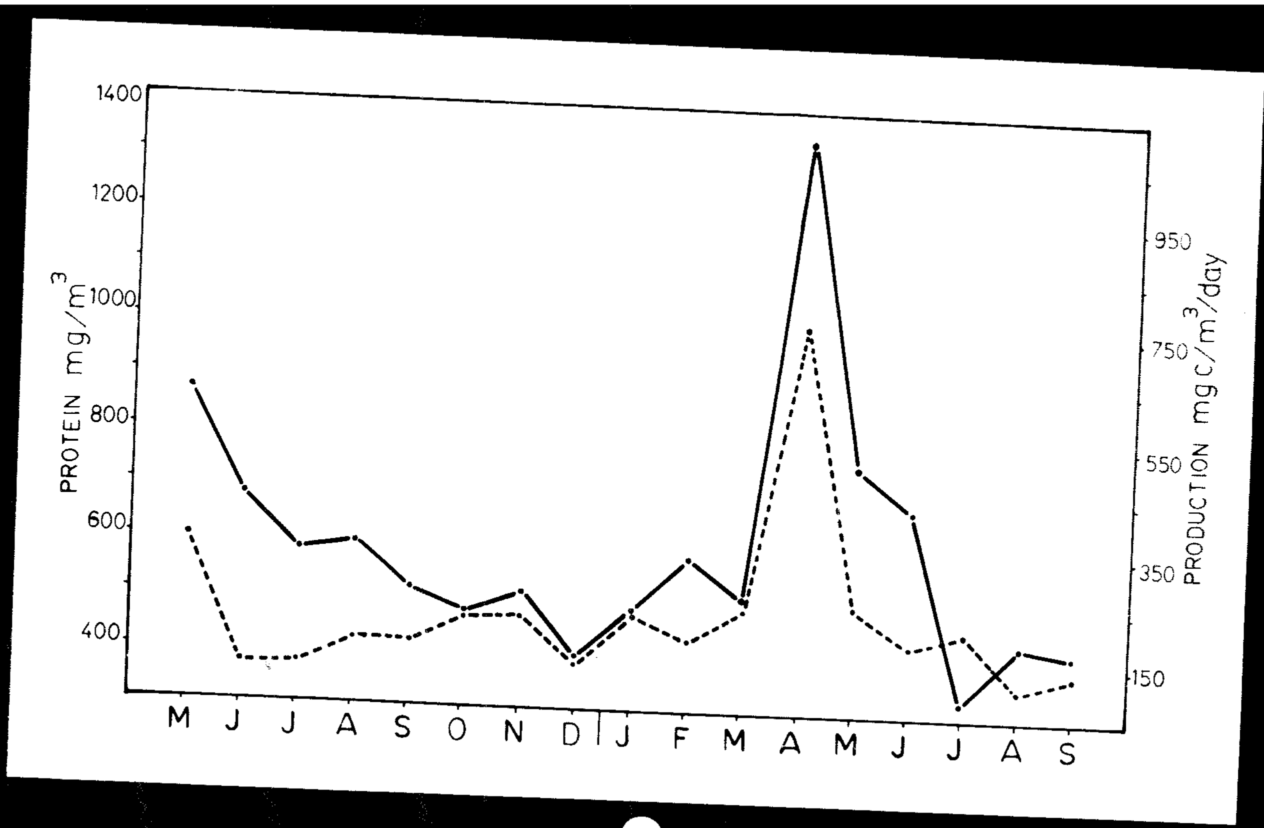
Table 23. Monthly variations of values of protein (N x 6.25) in particulate matter and primary production from the surface and bottom samples of Gulf of Mannar.

Period	Surface		Bottom	
	Protein mg/m^3	Primary production	Protein mg/m^3	Primary pro- $mg/m^3/day$
1959				
January	475.00	227.90	647.00	387.00
February	685.94	177.37	657.33	232.33
March	506.25	235.07	647.33	41.66
April	1350.00	761.10	946.33	757.66
1958				
May	875.00	350.45	1006.00	197.50
June	679.69	117.71	621.00	114.00
July	587.50	123.84	671.80	142.80
August	597.92	170.57	594.60	67.66
September	518.75	170.57	656.00	120.00
October	479.17	216.43	489.66	90.33
November	512.50	220.37	726.00	76.50
December	379.92	147.63	818.33	378.33

It is found that the trend in primary production is reflected in the values for protein obtained by this method. Both peaks coincide in April for the surface water (Fig.31). The individual values from all the analyses of the surface water ranged from 125 mg to 1450 mg per M^3 with the corresponding primary production being 60 and 760 mg/C/m^3/day. The trend was almost similar for the bottom water also but much lower values were obtained from the bottom samples. Disproportionaly large values for protein against primary production were obtained occasionally which could be either due to detritus or stray occurrence of zooplankters. However the mean values of both parameters showed a significant correlation at 5% level: the correlation coefficient being 0.3 for the surface and 0.36 for the bottom (Fig.32).

The estimation of total nitrogen in the particulate matter has certain obvious difficulties. As the amount of plankton in a sample of water is very small in comparison with dissolved organic matter it is not possible to determine the nitrogen content of the plankton by subtraction of the nitrogen content in a certain amount of filtered water from that of the same water without filtration. As particulate nitrogen occurs in planktonic algae and animals, bacteria and detritus, the contribution of any one of

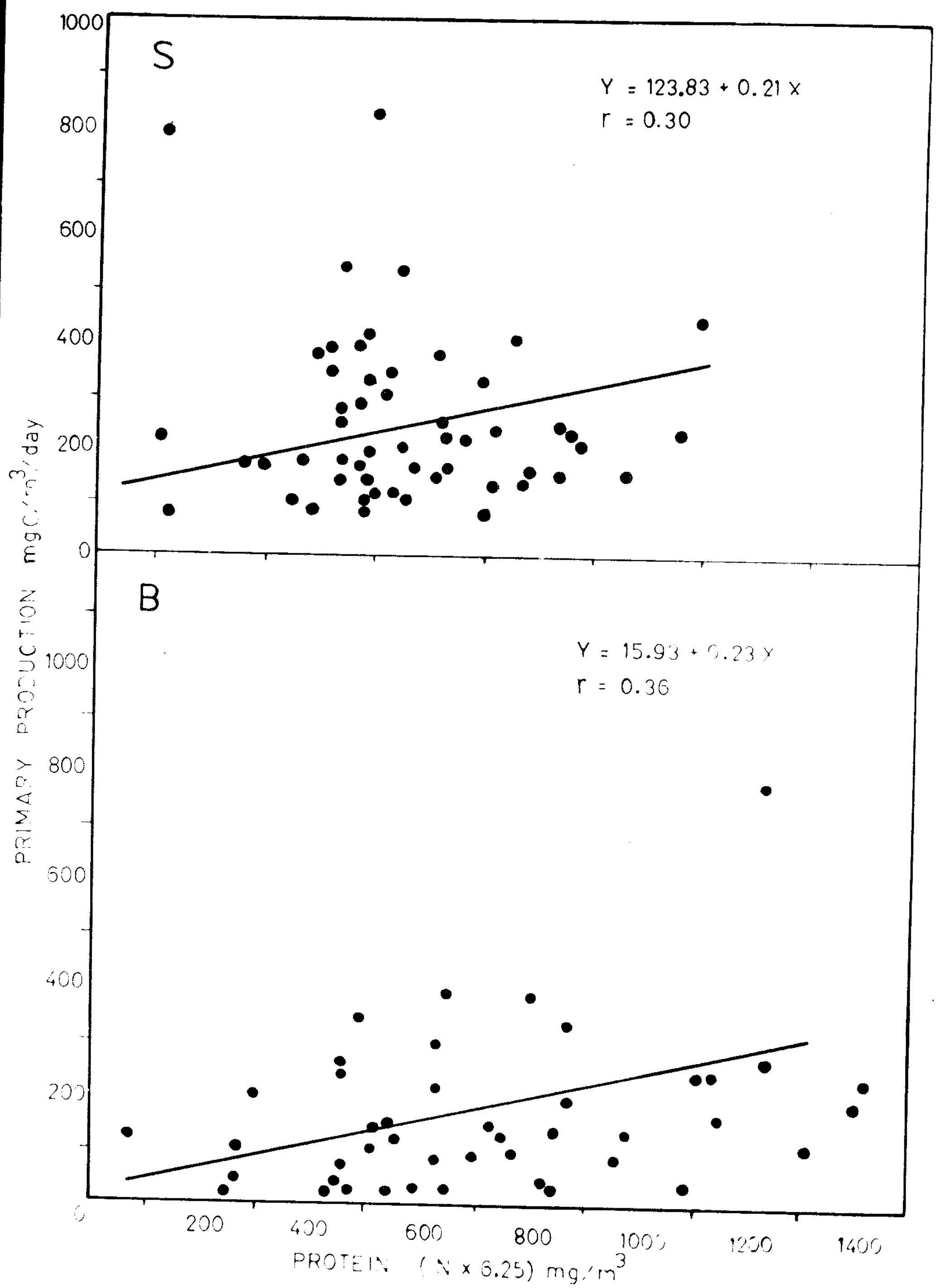
Fig.31. Seasonal variation of protein (N x 6.25) and primary production in the surface waters of the Gulf of Mannar during the period 1958 to 1969. Dashed line - primary production and continuous line - protein.



PROTEIN mg/m3
1400
1200
1000
800
600
400
PRODUCTION mg c/m3/day
950
750
550
350
150
M J J A S O N D J F M A M J J A S

31

Fig.32. Relationship between protein in particulate matter and primary production. S - surface samples and B - bottom samples.


S
Y = 123.83 + 0.21 X
r = 0.30
B
Y = 15.93 + 0.23 X
r = 0.36
PRIMARY PRODUCTION mgC/m³/day
PROTEIN (N x 6.25) mg/m³
0
200
400
600
800
1000
1200
1400

these categories is difficult to evaluate because of non-uniformity as to shape, number and particle size-distribution. Besides the nitrogen content of phytoplankton varies widely according to the state of nutrition of the cells.

Attempts to make a more direct routine estimate of protein have been undertaken by Krey (1951) and Strickland and Parsons (1960). The Krey method gives a certain differentiation between living matter and less reactive detritus. Steemann Nielsen (personal communication) also favours the Krey method than kjedlhal nitrogen method as the measure of an index of productivity.

Yentsch and Vaccaro (1958) have suggested that nitrogen may be estimated indirectly from a knowledge of the carotenoid chlorophyll a content of a phytoplankton crop. But this work applies only to culture and it has not been fully substantiated under natural condition with mixed population. Thus it is not certain that all forms of nitrogen are measured by the kjeldahl technique. Discrepancies that are sometimes observed lead one to suppose that some nitrogen may be missed or that substantial amounts of non-protein nitrogen may occur in certain samples (Yentsch and Vaccaro 1958, McAllister et al.1961, Parsons et al.1961). McAllister et al.(loc.cit.) reported a considerable discrepancy between the amount of protein obtained by the kjeldahl method (N x 6.25) and protein determined as casein. Hence, apart from serving as a crude index of standing crop, the total nitrogen values do not seem to hold much promise as an index of productivity.

PRIMARY PRODUCTION OF THE WORLD OCEANS AS COMPARED TO THAT OF THE INDIAN SEAS

During the last two decades several expeditions have collected extensive data from different parts of the world oceans. In addition, through individual efforts intensive data from many isolated regions have also been obtained. The first estimate of the primary production of the world oceans made by Riley (1944) was found to be 10 times higher by Steemann Nielsen after a round the world trip of GALATHEA (Steemann Nielsen and Aabye Jensen, 1957). Several attempts made subsequently at an evaluation of the world primary production indicated that the seas are not more productive than land and the magnitude is only because of the larger area. Recently Koblentz-Mishke et al.(1970) have reviewed the production of organic matter for the world oceans and got the figure which almost coincides with that of Steemann Nielsen's estimate. According to these authors the world production is $2.5 - 3.0 \times 10^{10}$ tons of carbon per year (gross) and $1.5 - 1.8 \times 10^{10}$ tons of carbon (net) is a more accurate figure. Gulland (1970) while assessing the fish resources of the world oceans has given a brief account of the primary production of the different regions. Cushing (1971) has estimated the total production in some of the upwelling regions of the world. Thus from the existing literature it is possible to derive a general idea of the magnitude of primary production in all the oceans.

Atlantic Ocean

Studies on primary production have been made by a large number of authors using a variety of methods in different parts of the Atlantic especially the north-eastern region. According to Steele (1965) the annual production is in the range of 50-150gC/m^2/year while Cushing considers the possible range as 40-200 gC/m^2/year. Assuming an average figure of 100 gC/m^2/year, Gulland (1970) has given a figure of 55×10^6 tons of carbon fixation for the north-east Atlantic.

During the survey of GALATHEA the highest rate of 3.8 gC/m^2/day and the lowest rate of 0.043 - 0.058 gC/m^2/day were observed in the Atlantic (Walvis Bay and Sargasso Sea respectively). The region of Benguela Current was found to be one of the most productive regions with a daily rate of 0.46 - 2.5 gC/m^2/day. In the Central part off the west coast of Africa the main areas of high production are the upwelling regions and oceanic areas along the equator. According to the seasonal variations in the rate of upwelling the rate of primary production also varies with the peak values reaching 5.2 gC/m^2/day off Dakar. Outside the peak season the rates fall to 0.2 - 0.4 gC/m^2/day (Steemann Nielsen and Aabye Jensen 1957; Sorokin and Kliashtorin 1961; Bessonov and Fedorov 1965). Off the coast of South America measurements have been made by Teixeira and Tundisi (1967). They have reported high values towards the coast decreasing seaward. In July/August higher values were found in the open ocean. El Sayed (1966) reported higher primary production off the Argentinean Coast than in Drake Passage and Weddel Sea. According to Mandelli and Orlando (1966), the Falkland Current is amongst the most productive area of the world oceans and also carries a permanent high phytoplankton biomass. The estimate of annual primary production in the Falkland Current is more than 200 gC/m^2 in the central part between 40° and 44°S and less than half as much in the southern parts (Gulland op.cit.)

The mean value given for the Atlantic by Koblentz-Mishke et al.(1970) is 190 mgC/m^2/day and 69.4 gC/m^2/year ~~for the Atlantic Ocean~~, which would amount to a net production of ca 5 x 10^9 tons per year. Of this the Benguela upwelling region alone accounts for 375 million tons of C/year which is a very high figure compared with those for other upwelling areas and bigger than the estimate for the Peru/Chile upwelling area (Cushing,1971). Outside the upwelling areas rate of primary production is at the moderate level typical of subtropical waters i.e., around 50 gC/m^2/year (Gulland,1970).

Primary production in the Mediterranean and Black Sea is generally low, but moderately high in some parts, especially in the Black Sea. Values for the Adriatic Sea also is high with 120 - 364 gC/m^2/year.

Pacific Ocean

Koblentz-Mishke (1965 and 1967) has reviewed the data on primary production from the Pacific Ocean. A band of high primary production with rates between 100 and 150 gC/m^2 extends along the North American coast to the tip of the Alaskan Peninsula and along the Aleutian Island chain including much of the offshore area of the Gulf of Alaska. The open oceanic part of the North Pacific is also noticeably more productive (50-100 gC/m^2/year) than the tropical and subtropical areas. The Puget Sound has a very high rate of 200-400 gC/m^2/year. On an average of 150 gC/m^2/year for the coastal strip, within 500 m contour the total annual primary production has been computed at 54 million tons (Gulland, op.cit.). Over 600 gC/m^2/year has been found in the south-eastern part of the Bering Sea (Ivanenkov, 1961). In the north-west Pacific highest production rate of 5 gC/m^2/day was recorded east of Hokkaido within the zone of convergence of warm and cold water. Taniguchi (1972) has calculated 89 gC/m^2/year in the Bering Sea, 156 gC/m^2/year in the Oyashio Current and 48 gC/m^2/year in the Kuroshio Counter Current. The North Equatorial Current showed the lowest rate of 33 gC/m^2/year. The waters of the South Equatorial Current (106 gC/m^2/year) and the region east of New Zealand (156 gC/m^2/year) were found to be more productive.

In the south-east Pacific, Gulland (1970) quotes Strickland, Eppley and Rojas de Mendiola that the annual production near the coast of Peru is more than 200 gC/m^2/year but suspect that the value will be considerably higher, possibly of the order of 500 gC/m^2/year. This could be in view of the recent measurement by Ryther _et al_. (1971) in a packet of newly upwelled water in the Peru Current of an average rate of 10 gC/m^2/day for five days. Cushing's estimate of total primary production in the Peru Current upwelling is 155 million tons of carbon of which about 45 million tons were estimated to be produced off Chile and the remainder off Peru. The average value for the Pacific Oceans as given by Koblentz-Mishke _et al_. (1970) is 127 mgC/m^2/day and 46.4 gC/m^2/year. According to these authors the Pacific Ocean is the least productive of all the oceans, whereas the Indian Ocean is the most productive. At the same time the yield ratio is considerably lower as compared to the Atlantic and Pacific Oceans. The potential yield in relation to primary production in the Indian Ocean and adjacent seas is discussed in the next section.

INDIA AND THE INDIAN OCEAN FISHERIES

India has a long coast line of nearly 6,000 km with the Andaman and Nicobar Islands and the Laccadive Archipelago lying beyond her shores. The geographical position of India with the peninsular portion extending deep into the central part of the Indian Ocean gives her a locational advantage in marine fishing activities. At present though India contributes about 40% of the fish landings of the Indian Ocean, when viewed against the world production of 60 million tonnes of marine fish, her share is only about 1 million tonne representing less than 2%. A quarter of a million persons are actively engaged in actual fishing producing annual landings valued at Rs.1,200 million. The industry also provides employment to 1.4 million persons. There are about 10,000 mechanised crafts which land 30% of the total production. Over 600 million rupees worth of sea food is exported to different countries.

Studies made during the International Indian Ocean Expedition as well as those conducted in the bordering countries reveal that there are several areas in the Indian Ocean which are exceptionally rich in nutrients, chlorophyll, organic production and zooplankton biomass. Consequently these areas could sustain large stocks of fish. This section deals with the present yield and its composition and the potential resources in the Indian seas and the Indian Ocean in general, as derived from productivity studies.

Topography

The Indian Ocean has an area of about 75 million square kilometres including Antartica and some of the adjacent seas, as against 106 million sq.km for the Atlantic and 180 million sq.km for the Pacific Ocean. The shallow water areas form about 3.1 million sq.km in the Indian Ocean. The shelf areas vary in width as well as in surface contour.

The west coasts of India, Ceylon and Pakistan have prominent shelves, whereas on the east coast the shelves are narrow. The east coast of Africa has a narrow shelf except at the southern-most tip. The coastal regions of Mozambique, Tanzania and Kenya are fringed with mangrove and coral reefs. The coasts of Burma, Thailand and Malaysia have a wide shelf with mangrove swamps. The west coast of Australia has a narrow shelf which widens towards the north. The western Indian Ocean Islands have banks which are of both volcanic and coral reef type. The availability of resources have thus to be viewed with the nature of the terrain for exploitation on a commercial scale.

Present yield and its composition

The fish landings in the Indian Ocean and the development during the last fourteen years as compared to the Atlantic and Pacific Oceans present a poor comparison both in the progress and also in the yield ratio in terms of primary production (Table 23).

Table 23. Fish landings during the past fourteen years and the present yield in terms of primary production for the different oceans

Ocean	Fish landings (Million tonnes)		Present yield as percentage of primary production (both in C)
	1958	1971	
Atlantic	13.6	23.32	0.04
Pacific	13.4	33.53	0.03
Indian	1.4	3.06	0.0075

The pattern of development in the world fishing shows that at the beginning of this century the total landings were only 4 million tonnes. By 1913 it had doubled to 9.5 million tonnes and again doubled by 1938 to 20.5 million tonnes. The marine fish production increased at the rate of 4.5% per year from 1952 to 1958 and picked up speed thereafter. In spite of a small drop during 1968 and 1971 the average growth rate for the preceeding ten years was 6.5% (Table 24).

Table 24. World production of fish and rate of increase during the last fourteen years.

Year	World production of fish (in million tonnes)	Rate of increase
1958	28.39	4%
1959	31.41	10%
1960	33.63	7%
1961	36.77	9%
1962	40.05	9%
1963	41.70	4%
1964	46.20	11%
1965	46.50	1%
1966	50.20	8%
1967	53.16	6%
1968	56.49	6%
1969	54.91	-2.8%
1970	61.28	11.6%
1971	60.55	-1.2%

This rate of increase is unparalelled by that for any other basic food commodity. Moreover, the future outlook is encouraging because according to the Indicative World Plan estimates, the world marine fish of currently exploited species with known techniques in areas already fished may amount to some 120 million tonnes by 1985. But the living resources of the sea are not limitless and higher yields will be possible only by envisaging utilisation of unconventional resources or aquaculture. The maximum yield in terms of carbon (which forms about 10% of the wet weight) is only 0.4% of the net primary production in the coastal areas (Steemann Nielsen, 1952) and in the oceanic areas considerably less. When viewed in this light India and the Indian Ocean countries have a challenging task to bridge the gap between the present yield and the possible production. Panikkar (1967) has visualised an output of 20 million tons of fish per annum from the Indian Ocean towards the close of this century.

Out of the present yield of 3 million tonnes from the Indian Ocean, western region accounts for 1.9 million tonnes. The Arabian Sea provides 15,00,000 tonnes and Bay of Bengal 8,40,000 tonnes. The group of fishes consisting of herrings, sardines, anchovies and related forms contribute about 28% of the total catch from the Indian Ocean. Red fishes, basses and congers come next with 19% of the total yield. The crustaceans account for 12% of the average annual landings of which India's share at present is about 150,000 tonnes, consisting mainly of shrimps. Tunas, bonitos and skipjack account for 11% and the group consisting of mackerels, bill fishes, etc., account for 8.6%.

<u>Primary production and potential yield</u>

When primary production is considered in the overall role of food chain relation in the sea it becomes necessary to know the efficiency of energy transfer from one step in the food chain to another. This is one of the least known aspects of the food chain dynamics in the sea. All food chains from phytoplankton herbivores and upwards tend to become intermeshed and forms a food web rather than a chain. Many organisms feed at more than one level of the food chain. When the steps are few in the food chain higher efficiencies of food energy transfer are obtained. The most important direct consumers of phytoplankton are the copepods and euphausids. These crustaceans and their larvae constitute the bulk of the food of the other plankton animals including pelagic fish larvae and the plankton feeding fish. The most important plankton feeding group of fishes are the clupeoids which constitute about 30% of the marine fish catch. A small fraction of the production (1-10%) reach the bottom and serve as a food source for the bottom fauna.

It has been observed that the landing of commercial fish in intensely exploited waters is about 0.4% of the organic matter produced by the phytoplankton. Even though the percentage utilisation does not seem to be high it is the highest that is found in the sea.

The data are now available from various sources on standing crop, primary production, chlorophyll values and exploratory fishing reports. Hence it is possible to make a broad appraisal of the potential resources.

The distribution pattern of chlorophyll in the Indian Ocean shows that the level of pigment concentration per unit area is almost the same to that of Atlantic and Pacific Oceans even though the concentration per unit volume is slightly lower. (Humphrey, 1966).

The average amount of chlorophyll a for the entire Indian Ocean is found to be 14.81 mg/m^2 (integrated values upto 200 metres). For the west coast of India the integrated mean value is 25.41 mg/m^2 while for the east coast it is only 8.24 mg/m^2. In the western Indian Ocean during the south-west monsoon extremely high values are found mainly in the area off Cape Guardafui and Socotra in the upwelling regions associated with Somali current. High values of primary production and zooplankton biomass are also observed in this area. (Prasad, 1969; Prasad, Banerji and Nair, 1970). Laird, Breivogel and Yentsch (1964) observe that in terms of potential fisheries, the high chlorophyll values along the Somali coast are of interest. The productivity of such areas in terms of carbon fixed per square metre per day is about 4-5 grams. If the rate of production is steady during the monsoon period the total production would be about 350-450 gC/m^2. In terms of dry weight of algae it amounts to 800 g/m^2 which ranks this area among the most productive. Hence the authors believe that the area off the Somali coast, longitude 57°E between latitude 10°N and the equator could support excellent fisheries during the south-west monsoon period.

There is great amount of spatial variation in the magnitude of primary production in the Indian Ocean. The shelf areas which sustain the bulk of the fish production at present are on the whole having a high rate of production. Because of the constant replenishment of nutrients in the surface layers the shallow water areas of the tropics are generally productive. An average rate of 0.5 to 1.0 $gC/m^2/day$ is observed in the shallow areas most of the time. Rates exceeding 2 $gC/m^2/day$ are found during the south-west monsoon.

In the eastern Arabian Sea towards the coast of India the average rate within 50 metre depth is about 1.2 $gC/m^2/day$ and for the outer shelf regions the rate is < 0.5 $gC/m^2/day$. The net production (taken as 60% of the gross) for the shelf area on the west coast of India within 50 metres (114,520 sq.km) has been estimated as 30×10^6 tonnes of carbon. Between 50 and 200 metres (168,790 sq.km) the net production is only 16×10^6 tonnes. Thus for the whole continental shelf area on the west coast of India the annual net production is computed at 46 million tonnes of carbon.

Schaeffer (1965) has tried to estimate the potential harvest of the sea from net production of the world oceans by assuming different ecological efficiency factors obtained experimentally by Slobodkin (1959). Accordingly the potential yield for the west coast of India at different trophic levels will be as given below:

Estimates of potential yield at various trophic levels (in tonnes)

Trophic level	Ecological efficiency factor					
	10%		15%		20%	
	Carbon	Total wt.	Carbon	Total wt.	Carbon	Total wt.
0) Net primary production	3×10^{7}		3×10^{7}		3×10^{7}	
1) Herbivores	3×10^{6}	3×10^{7}	4.5×10^{6}	4.5×10^{7}	6×10^{6}	6×10^{7}
2) 1st stage carnivores	3×10^{5}	3×10^{6}	6.8×10^{5}	6.8×10^{6}	12×10^{5}	12x10[illegible]
3) 2nd stage carnivores	3×10^{4}	3×10^{5}	10.2×10^{4}	10.2×10^{5}	24×10^{4}	24x10[illegible]
4) 3rd stage carnivores	3×10^{3}	3×10^{4}	15.3×10^{3}	15.3×10^{3}	15×10^{3}	48x10[illegible]

Since it is difficult to assign a proper trophic level to the different categories of fishes as they may belong to more than one trophic level, on assumption that if the harvest is all taken at step 3, the following will be the potential yield for the west coast of India for the various ecological efficiency factors:

Ecological efficiency factor	Total biomass of fish (tonnes)
10%	3,00,000
15%	10,20,000
20%	24,00,000

As the present yield is about thrice the figure at 10% level it may be considered that harvesting at stage 3 at 10% efficiency factor is too low. At 15% efficiency factor the biomass should be 1 million tonnes and at 20% efficiency 2.4 million tonnes. However, if it is assumed that half of the potential could be taken at step 2 as pelagic fishes which feed on phytoplankton or a mixture of phytoplankton and zooplankton and another half at step 3 which is more realistic (Schaeffer loc.cit.) the available potentials would be as follows:

Ecological efficiency factor	Total biomass of fish (tonnes)
10%	16,50,000
15%	39,10,000
20%	72,00,000

Taking various factors into consideration such as depletion of stock from predation, economic viability etc., a potential harvest of at least 2 million tonnes from the west coast is a modest estimate (i.e. 50% of the biomass at 15% ecological efficiency).

The optimum yield from primary production in intensely exploited waters being 0.4%, the potential yield could be computed as $\frac{0.4 \times 46 \times 10^6}{100}$ = 184,000 tonnes of carbon=1.84 million tonnes of fish. The latest figure for 1971 being

904,400 tonnes there seems to be scope for doubling the present catch.

On the east coast the net production has been estimated at 15 x 10^6 tonnes. This may be an under estimate due to lack of sufficient data. But the shallow areas on the south-east coast being highly productive it is possible that a higher annual net production could be envisaged. So assuming as before that half is taken at steps 2 and 3 the potentials will be as follows:

Ecological efficiency factor	Total biomass of fish (tonnes)
10%	8,25,000
15%	19,55,000
20%	36,00,000

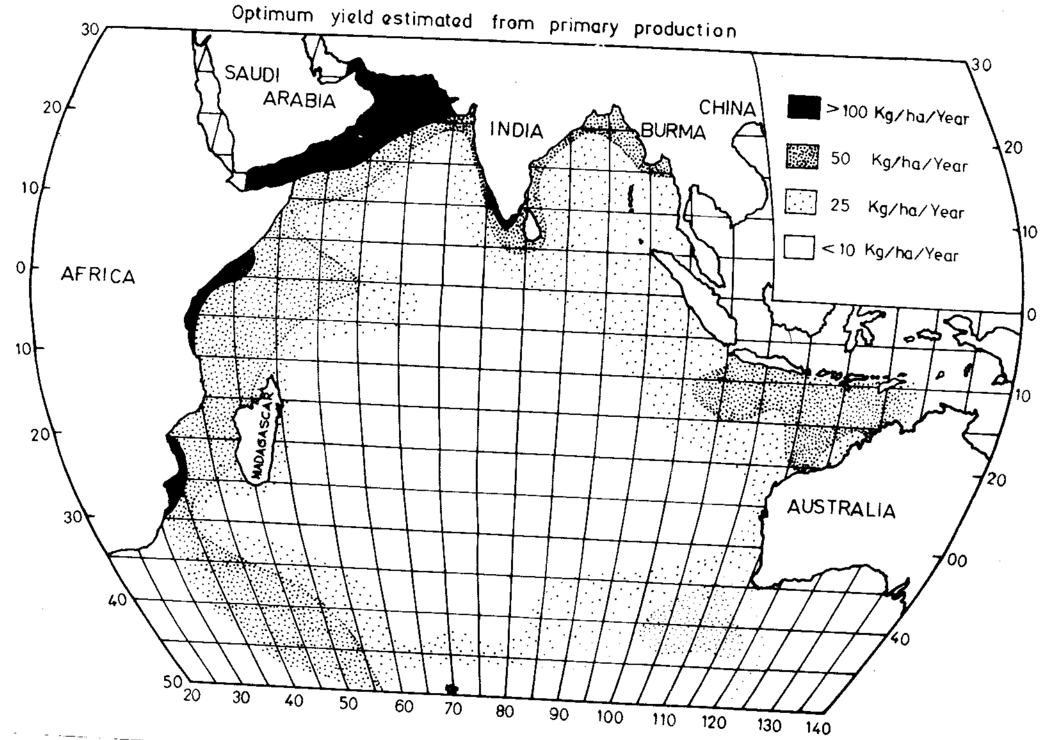
That amounts to 50% of the west coast production or 1 million tonnes instead of the present catch of 250,000 tonnes. Thus the potential harvest for the whole Indian coast is about 3 million tonnes of fish, which is about the yield from the Indian Ocean at present.

Prasad, Banerji and Nair (1970) made a quantitative assessment of the potential resources of the Indian Ocean from primary production and zooplankton biomass and examined it in the light of the results of exploratory fishing conducted at various regions. The net primary production for an area of 51 million square kilometres of the Indian Ocean has been computed as 3.9×10^9 tonnes of carbon per year. This is in close agreement to the estimate of Koblents-Mishke et al., (1970) i.e. 4.1×10^9 tonnes.

An estimate of the possible catch at the present level of world fishing is 11-12 million tonnes. This figure has been arrived at by comparison of the yield ratio in the Indian Ocean to that of the Atlantic and Pacific Oceans. But the potential harvest derived from estimates of fish biomass based on primary production and its subsequent transfer through the various trophic levels could be as high as 39-40 million tonnes. As mentioned before, in heavily exploited waters as in the North Sea and the English Channel, where optimum catch is obtained, it has been observed that carbon content of optimum fish catch divided by net production which is 60% of gross production gives a ratio of 0.004. Hence the potential yield is about 105 kg per hectare (Fig.33). Based on primary production data the probable potential increase has been worked out for the various regions (Table 25).

Fig.33. Optimum yield of fish in different regions of the Indian Ocean as estimated from primary prodution data.

Fig.34. A pictorial representation of the composition of the potential yield estimated from different regions of the Indian Ocean based on exploratory survey reports. D - demersal fishes, P - Pelagic fishes, C - crustaceans and T - tunas.


Optimum yield estimated from primary production
SAUDI ARABIA
INDIA
BURMA
CHINA
AFRICA
MADAGASCAR
AUSTRALIA
> 100 Kg/ha/Year
50 Kg/ha/Year
25 Kg/ha/Year
< 10 Kg/ha/Year

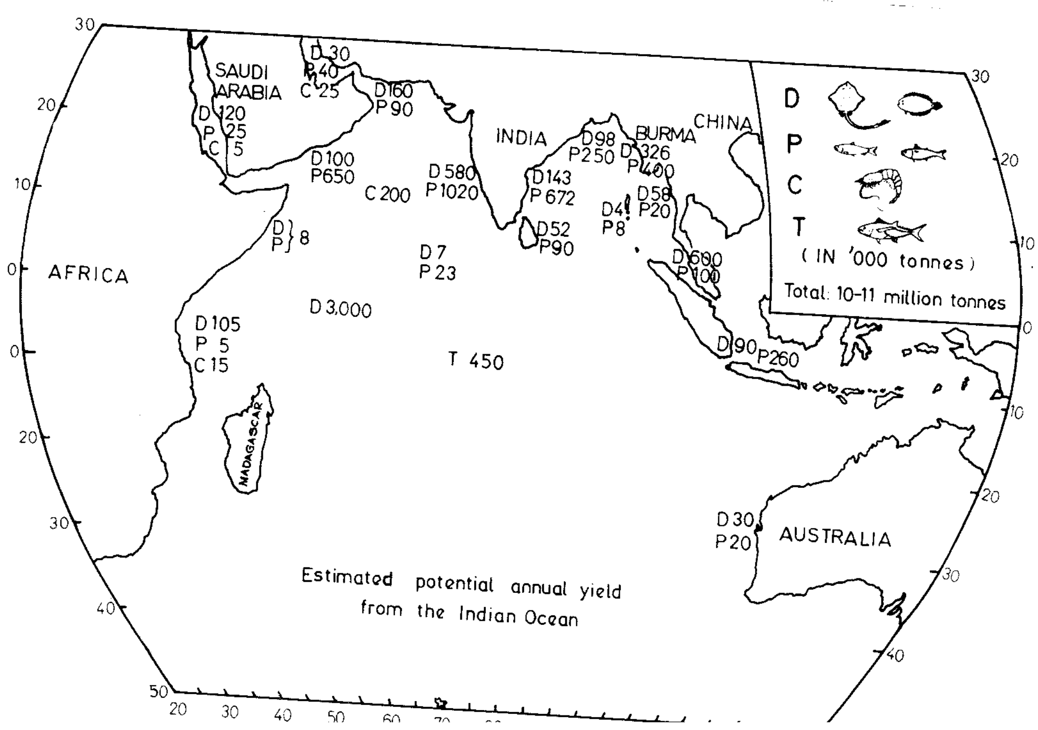

Estimated potential annual yield from the Indian Ocean
SAUDI ARABIA
INDIA
BURMA
CHINA
AFRICA
MADAGASCAR
AUSTRALIA
D 30 P 40 C 25
D 160 P 90
D 120 P 25 C 5
D 100 P 650
C 200
D 580 P 1020
D 98 P 250
D 326 P 400
D 143 P 672
D 58 P 20
D 4 P 8
D 52 P 90
D 600 P 100
D P 8
D 7 P 23
D 3,000
D 105 P 5 C 15
T 450
D 90 P 260
D 30 P 20
D
P
C
T
(IN '000 tonnes)
Total: 10-11 million tonnes

Table 25. Present yield as %0 and the probable potential increase for the various regions of the Indian Ocean

Region	Yield rate as %0	Probable potential increase
Atlantic	0.04	-
Pacific	0.03	-
World Oceans (mean)	0.03	-
Indian Ocean (total)	0.008	x 5
Continental shelf of Indian Ocean	0.03	x 10
Gulf of Mannar	0.07	x 5
West coast of India	0.22	x 2
East coast of India	0.14	x 3

The estimates of potential yield becomes meaningful only when they are compared with the results of exploratory surveys. The potential yield of fish for the entire continental shelf area of India as estimated by Jones and Banerji (1968) has been found to be 2,288,000 tonnes of which the share of the west coast is 1,417,000 tonnes. This estimate includes both pelagic and demersal fish. The percentage of demersal fish in the total catch varied from 28 in 1966 to 36.8 in 1969 (Table 26).

Table 26. Catch from exploited stock. Estimated region-wise distribution of pelagic and demersal fish catch based on the data collected by the Central Marine Fisheries Research Institute for 1969

State	Pelagic	Demersal	Total
Gujarat	63,868	18,380	82,248
Maharashtra	75,940	92,780	1,68,720
Goa	25,678	1,881	27,559
Mysore	58,904	16,889	75,793
Kerala	2,09,988	84,799	2,94,787
Tamil Nadu	73,962	77,914	1,51,876
Pondicherry	7,079	3,558	10,637
Andhra	47,680	29,846	77,526
W.Bengal & Orissa	12,967	9,912	22,879
Laccadives	884	309	1,193
Andamans	262	150	412
TOTAL	5,77,212	3,36,418	9,13,630

Assuming the ratio of demersal fish to be 30% on an average, the potential demersal catch for the entire Indian shelf area will be 7,00,000 tonnes and the potential pelagic yield about 1,600,000 tonnes. If intensive exploitation is possible for the entire shelf area of the Indian Ocean which comprises 307 million hectares, it would be possible to obtain an yield of 11 million tonnes from these areas. Hence theoretically a four-fold increase from the present level of exploitation should be possible even from the stocks available within the continental shelf with India's share between 2 and 3 million tonnes or almost the present production from the entire Indian Ocean.

When these theoretical estimations are examined in the light of exploratory fishing data, available through many reports which have appeared in recent years, a more or less same picture is obtained (Anon, 1958 a, b; Losse, 1963; Masuda et al. 1964; Mietle, 1967; Postel, 1965; Reed, 1964; Rhodes, 1966; Shomura et al. 1967; Tiews, 1966; Wheeler and Ommanney, 1953; Rao, 1969; Silas, 1969).

As assessed from these exploratory surveys, the potential catch from the East African coastal fishery is 1,25,000 tonnes of fish. Demersal fishery of the offshore banks is considered to be very high amounting to 2-3 million tonnes. The potential yield from the Arabian Sea region has been estimated at 8,50,000 tonnes of demersal fish and 1,790,000 tonnes of pelagic fish with sizeable proportion of crustaceans amounting to 2,00,000 tonnes. Including the Red Sea and Persian Gulf resources the annual potential yield for the western Indian Ocean has been estimated at 6 million tonnes (Prasad, Banerji and Nair, 1970).

For the Eastern Indian Ocean the potential yield is 1,281,000 tonnes of demersal and 1,540,000 tonnes of pelagic fish. Including Indonesian waters and Australian shore the potential yield has been estimated at 3.22 million tonnes. With the oceanic tuna resources the potential yield as deduced from the exploratory surveys is about 10-11 million tonnes of fish (Table 27; Fig.34).

Table 27. Annual potential yield from the Indian Ocean (in 1000 tonnes)

Zone	Demersal (incl.crustaceans)	Pelagic	Total
East African coast	120	5	125
East African Offshore bank	3000	-	3000
Somalia	-	-	8
South Arabia, Muscat, Oman	100	650	750
West Pakistan	160	90	250
India (west coast)	580	1020	1600
Maldives,Laccadives,Chagos	7	23	30
Red Sea	125	25	150
Persian Gulf	55	40	95
India (east coast)	143	672	815
East Pakistan	98	250	348
Burma	326	400	726
Thailand (west coast)	58	20	78
Malaysia (west coast)	600	100	700
Ceylon	52	90	142
Andaman and Nicobar	4	8	12
Indonesia	90	260	350
Australia	30	20	50
Oceanic Tuna	-	-	450
TOTAL	-	-	9,679 or 10 million

The share of Indian seas towards the total production of fish from the Indian Ocean is thus 2.4 million tonnes (1.6 million tonnes from the west coast and 0.8 million tonnes from the east coast). This would mean a nearly three-fold increase from the present level of exploitation. The rather close similarity in the figure obtained from the data on primary production as well as exploratory fishing is striking and lends validity to each other.

S U M M A R Y

This account deals with the results of investigations on primary production and related aspects conducted in the Indian Seas since 1957 and includes the regional and seasonal variations in the rate of production, factors controlling the same and the magnitude of potential fishery resources derived from it.

Data collected for various periods using oxygen ^{14}C techniques from the Gulf of Mannar, Palk Bay, the south-west coast of India including Laccadive Sea together with other available data form the basis of these studies.

Intensive trials on standardisation and intercalibration have been carried out to make the ^{14}C data reliable and comparable. The results are presented along with the material and methods.

It is found that the shallow regions of the Gulf of Mannar and Palk Bay are very productive with an annual gross production of 443 and 561 gC/m^2, respectively.

On the west-coast the maximum production is towards the coast within 50 m depth and gradually decreases seawards. The mean value within 50 m is 1.24 gC/m^2/day with the highest rate during the south-west monsoon season.

The minimum is during the pre-monsoon when the mixed layer is deepest and moderately high rates are found during the post-monsoon. The daily rate of production for the rest of the shelf is 0.47 $gC/m^2/day$ and for oligotrophic regions outside the shelf it is only 0.18 $gC/m^2/day$.

The annual gross production for the inshore regions on the west coast within 50 m is 453 gC/m^2 and for the rest of the shelf 170 $gC/m^2/year$. This would amount to an annual gross production of 50×10^6 tonnes of carbon for the inshore regions comprising 1,14,520 sq.km and 30×10^6 tonnes for 1,68,790 sq.km of the outer shelf regions.

The rates of primary production for the east coast are 0.63 $gC/m^2/day$ on the shelf and 0.19 $gC/m^2/day$ outside the shelf and annual estimated gross production is 25×10^6 tonnes of carbon for 1,11,150 sq.km of the shelf.

By comparison with areas where there is intensive exploitation and by tracing the carbon production through the different trophic levels using various ecological efficiency factors an estimate of a potential harvest of 3 million tonnes of fish has been derived for the Indian Seas which is about three times the present yield. The results of exploratory surveys indicate a potential yield of 2.4 million tonnes from both the coasts, lending validity to the estimates from primary production data.

Similar calculations have been made for 51×10^6 sq. km of the Indian Ocean for which the Indian Ocean Expedition data are available. The annual net production is computed at 3.9×10^9 tonnes of carbon which is about one-fifth of the estimated world oceanic production, while the catch is only one-twentieth of the world production of marine fish. The shelf areas of the Indian Ocean alone account for 0.56×10^9 tonnes of carbon or about one-seventh of the total production in the Indian Ocean. The potential yield from the Indian Ocean at the present level of world fishing is about 11 million tonnes of fish. The Indian Seas could provide an annual sustainable yield of about one-fourth of the potential yield from the Indian Ocean as the productivity studies indicate.

In addition, the growth kinetics of the common phytoplankters in natural conditions and a green flagellate, *Tetraselmis* in culture have been presented.

The factors controlling production have been discussed. The availability of nutrients has been found to be the principal factor that determines the seasonal and regional variation of primary production in the Indian Seas.

The variations of the three phosphorus fractions - inorganic, organic and particulate P have been discussed in relation to the primary production in Gulf of Mannar off Mandapam. Though the rate of primary production is uniformly high, instantaneous concentration of inorganic P is low and without significant seasonal variation. But the total P, dissolved organic P and particulate P show definite seasonal variation. From primary production the rate of phosphate assimilation and regeneration have been deduced.

Total organic nitrogen values in the particulate matter converted into protein equivalents exhibit a significant correlation with primary production. However, it is found that apart from serving as a crude index of standing crop, the method does not seem to hold much promise due to the errors involved.

Four collaboration papers - one on the quantitative assessment of the potential resources of the Indian Ocean and adjoining seas, two on the primary productivity of some of the coral reefs in the Indian Seas and one on the ecology of a tidal pool are appended.

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A QUANTITATIVE ASSESSMENT OF THE POTENTIAL FISHERY RESOURCES OF THE INDIAN OCEAN AND ADJOINING SEAS

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The Indian Ocean as conventionally described includes the Antarctica also, and has an area of 74·917 million sq km (Sverdrup *et al.*, 1946). The authors for the purpose of this study have taken the region between 20° and 120° E longitudes and from the Asian land mass in the north to 45° S latitude. The area thus considered covers over 51 million sq km or roughly two-thirds of the conventional Indian Ocean.

On its periphery live about 500 million people whose per capita consumption of fish does not exceed 1 to 2 kg per year, which is only one-tenth of that of some developed countries. The present catch from the countries bordering the Indian Ocean is about 2·1 million tonnes according to FAO Yearbook, and 2·5 million tonnes according to Panikkar (1967). This in terms of unit area is about one-fourth to one-sixth of the present yield from the Atlantic and Pacific Oceans (Shomura *et al.*, 1967). Hence when the International Indian Ocean Expedition (IIOE) was conceived the main emphasis, apart from understanding a least-known ocean, was the assessment of the fishery resources for increased utilization to augment the protein food of the people in the surrounding regions.

As a first step the distribution of zooplankton biomass in the Arabian Sea, Bay of Bengal and the entire Indian Ocean was studied (Prasad, 1968a, b). This was based on the volumetric analysis of the standard zooplankton samples deposited at the Indian Ocean Biological Centre. This study provided useful information on the relative productivity of the various regions of the Indian Ocean. Based on this, Prasad (1969) discussed the distribution of zooplankton biomass in the Arabian Sea and Bay of Bengal, and the fisheries of the regions. These studies provided a general picture of the areas rich in plankton and the relative magnitude of the fishery resources as they existed. In this paper, based on the zooplankton data, a quantitative estimate of potential yield of fish has been worked out along with an independent assessment using C^{14} primary productivity data, tracing the carbon production through the various trophic levels. These appraisals have been compared with a review of the results of exploratory surveys conducted by various agencies at different periods in the Indian Ocean region.

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d Malaysia have a wide shelf area with mangrove swamps. The west coast of stralia has narrow shelf, less than 65 km wide in the south-western part, whereas thward the shelf becomes wider. In the north-west area of the continent the shelf eeds 320 km in width. The western Indian Ocean Islands (Comoro, Mauritius, union, Seychelles, Chagos, etc.) have banks which are of both volcanic and coral f type.

PRODUCTION IN THE OCEANS AND TREND OF FISHERY

To obtain an adequate notion of the importance of primary productivity in the logical household of the sea, it is necessary to estimate the total turnover of matter d the yield in terms of fish. Riley (*vide* Rabinowitch, 1945) showed that the oduction of organic matter does not change much from the equator to the Polar cle and that the average of all measurements is 375 kg of organic carbon annually r sq m corresponding to 3·75 tonnes per ha. Hence according to Riley's estimate r 361×10^6 sq km of sea the production amounts to $15 \cdot 5 \times 10^{10}$ tonnes which is ght times higher than the carbon fixation calculated for land. But Steemann elsen (1954) questioned the validity of this estimate. From *Galathea* Expedition ata, he estimated the annual production of the hydrosphere (*vide* Steemann Nielsen d Jensen, 1967) to be $1 \cdot 2 - 1 \cdot 5 \times 10^{10}$ tonnes of carbon (net production after allow- g 40 per cent for respiration), which was practically the same as the earlier estimate land. Ryther (1959) considered this estimate to be lower as it has been based single observations and does not include seasonal maxima. His own estimate is at the seas are twice as productive as land. If a total annual production of $1 \cdot 9 \times 10^{10}$ tonnes of carbon for all the seas is assumed (*vide* Schaefer, 1965), the present h production of 54 million tonnes would represent only 0·03 per cent of net produc- n. According to Steemann Nielsen and Jensen (1957), in eutrophic areas at higher titudes, e.g. the North Sea, about 0·2–0·3 per cent of the carbon annually fixed by the ankton algae is taken every year by the fishermen. With improved methods of tching, the optimum seems to be at 0·4 per cent. Such a high percentage of yield possible only in coastal areas where the main fishery harvest consists of anchovies, rdines, herring and the like, some of which feed almost entirely on phytoplankton d others which feed on a mixture of phyto- and zoo-planktons. When the harvest from higher trophic levels the potential yield is likely to be less.

Schaefer (1965) recently attempted to estimate the potential yield of the sea by lculating the harvestable crop from the net carbon production and its subsequent ansfer through the food web. He considers a production of 200×10^6 tonnes of fish r the world oceans as reasonable and probably conservative. That would mean a ur-fold increase from the present level of exploitation. Some experts believe that ith the present trend of increase in the marine-fish production an increase to 100 illion tonnes by the end of this century should be possible. The target set for 1970, z. 55 million tonnes of marine fish, has nearly been achieved even in 1967 when the arine-fish production was estimated at 54 million tonnes (FAO Yearbook, 1967).

The Indian Ocean has been a comparatively under-exploited area. The present eld is roughly 2·5 million tonnes and it is believed that the output could reach 20 illion tonnes per annum towards the close of this century (Panikkar, 1967).

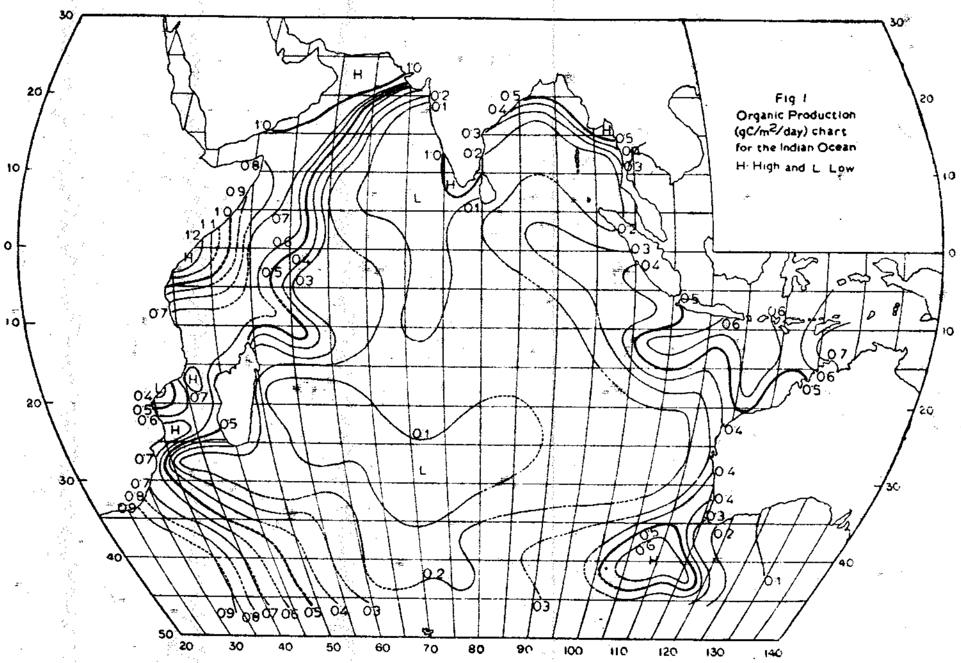

FIG. 1.

rate, 0·22–0·23 gC/m²/day, was found. The coast of Ceylon has a high production rate. Very high values were observed south-east of Java and this region has been shown recently to have upwelling, fairly high concentration of inorganic phosphate at the bottom of the euphotic layer and a high plankton biomass (Wyrtki, 1962). Summarizing all the *Galathea* measurements in the equatorial current systems of Indian Ocean, Steemann Nielsen and Jensen (1957) concluded that the rate of production is moderately high in the whole region of the equatorial current systems and in restricted areas very high rates of production are found.

Kabanova (1961) reported that primary production in the open part of the ocean was low and did not exceed 0·01–0·03 gC/m²/day. An increase in the value of primary production was observed in coastal waters and in the zones of ascent of deep water. In the Banda Sea the production reached 0·236 gC/m²/day, while on the Australian shelf the value increased up to 0·45 gC/m²/day. In the African-Madagascar region it was 0·072 gC/m²/day. The Arabian Sea water was characterized by an especially high productivity connected with the presence of regions of deep-water ascent.

For the western Indian Ocean, Ryther *et al.* (1966) observed two large areas of low productivity, one to the north extending from 80° to nearly 60° E Long., and from the Indian Continent to about 5° S Lat., and another from 10° to about 40°S Lat. and from 80° Long. nearly to the African coast south of Madagascar. *Anton Bruun* measurements do not include any from near the coast. Nair *et al.* (1968) found that the level of organic production is high towards the coast and becomes less sea-ward. Values over 2·0 gC/m²/day are obtained within 50 m depth. Over th Wadge Bank at a station 38 m deep, the production rate was 2·09 gC/m²/day. Jus below the surface the rate per unit volume was 12 mgC/m³/hour, suggesting a constan replenishment of nutrients. The highest value of 4·55 gC/m²/day was observed a a station on the Wadge Bank in September. The annual rate of gross productioı was 434 gC/m² on the shelf within 50 m depth, 157 gC/m²/year between 50 anc 200 m and 50 gC/m²/year outside the shelf.

Ryther *et al.* (1966) noticed moderately productive waters (0·26–0·50 gC/m² day) between 5° and 10°S Lat. Pockets of high productivity (>1·00 gC/m²/day) were noted along the south-east coast of Durban, Laurenceo Marques and Béira On the seaward side of Agulhas Current relatively low levels of productivity were encountered.

North of the equator and into the Arabian Sea the level of organic production increases to the north and west, reaching exceptionally high values off the coasts of Saudi Arabia and West Pakistan. The average for 23 measurements in that region was more than 1·0 gC/m²/day, with a maximum of 6·4 gC/m²/day observed off the south-eastern tip of Arabia. This value is the highest so far recorded from the oceans. Based on these measurements, Ryther *et al.* (1966) calculated that for the western Indian Ocean, where the *Anton Bruun* survey was carried out for an area of 23×10^6 sq km (about half of the Indian Ocean region now being considered, or one-third of the Indian Ocean as conventionally mentioned), the annual productivity is 3×10^9 tonnes of carbon which gives an average of 0·35 gC/m². But because of the great contrast in the relative productivity in this region the average value has not much significance. About half of the total production occurred in 20 per cent of the area surveyed.

Mitchell-Innes (1967) found for the region off South Africa, between latitudes 26° and 47°S, values ranging from 0·03 to 1·08 gC/m²/day. High productivity was observed (>0·5 gC/m²/day) in Delgoa Bay and off Port Elizabeth. Burchall (1968 a, b) observed values ranging from 0·02 to 0·94 gC/m²/day in the Agulhas Current region off Natal. Areas of high primary production were located in the vicinity of the continental shelf and also at the eastern boundary of the Agulhas Current. The average net production for the western half of the Indian Ocean is a little higher than the eastern half*. Over the shelf the annual average is more than double that of outside.

Allowing 40 per cent of the organic production for respiration, the average net production for the western and the eastern half of the Indian Ocean are about 0·24 and 0·19 gC/m²/day, respectively. The difference is mainly brought about by the high rates of production obtained on the western Arabian Sea and the continental shelf areas on the west coast of India. The net production of carbon for the western half comprising 29×10^6 sq km is $2{\cdot}3 \times 10^9$ tonnes of carbon per year and that for the eastern half comprising 22×10^6 sq km is $1{\cdot}6 \times 10^9$ tonnes a year. These are, however, from the mean values including the oceanic regions.

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*80° E Long. is taken as the boundary separating the western and eastern Indian Ocean.

If the present level of exploitation for the oceans in terms of carbon is taken into consideration, the total yield works out to only 0·03 per cent of the net production. The present yield of 2·1 million tonnes of fish from the Indian Ocean and adjacent seas in terms of carbon is about 0·005 per cent, hence a six-fold increase seems possible to bring the level of exploitation to that of Atlantic and Pacific Oceans in view of the general level of productivity.

On the continental shelf the rates are uniformly high during most part of the year. The mean net production is 0·51 gC/m²/day. This value is only minimal in view of the results of experiments conducted at several shelf stations for prolonged periods. As has been pointed out earlier, values over 1·0 gC/m²/day are often met with in near-shore stations within 50 m depth, especially during upwelling. Hence the annual net production for $3 \cdot 1 \times 10^6$ sq km of the shelf area would amount to 560×10^6 tonnes. Thus, approximately 6 per cent of the area produces one-seventh of the entire organic carbon in the Indian Ocean. In eutrophic coastal areas where it is possible to exploit 0·2 to 0·3 per cent or even up to 0·4 per cent of the carbon production, the minimum yield over the shelf itself would amount to 11×10^6 tonnes. Hence theoretically a six-fold increase from the present level of exploitation should be possible even from the stocks available within the continental shelf. To test the tenability of this hypothesis, the results of exploratory surveys conducted by various agencies at different periods were examined. Before giving an assessment of the potential yield based on the various exploratory surveys, the details of present yield and its composition are given below.

PRESENT YIELD AND ITS COMPOSITION

The average annual yield from the Indian Ocean region is a little over 2·1 million tonnes (FAO Yearbook, 1967). The contribution from the East African coast region is about 58·7 thousand tonnes. The country-wise details (in thousand tonnes) are as follows: South Africa, 3·0; Mozambique, 5·8; Tanzania-Tanganyika, 16·8; Tanzania-Zanzibar, 10·1; Kenya, 6·2; Madagascar, 9·8; Mauritius, 1·4; Seychelles, 1·5; Comoro Islands, 1·6; and Reunion Islands, 2·5.

The average yield from the Arabian Sea region is about 9,39,600 tonnes; the country-wise break-up (in thousand tonnes) is as follows: Somalia, 4·5; French Somaliland, 0·7; Federation of South Arabia, 52·2; West Pakistan, 117·2; West Coast of India, 648·8; Laccadives, 0·7; Maldives, 15·5; and Muscat and Oman, 100·0.

The average yield from the Red Sea region is about 45,300 tonnes. The country-wise break-up (in thousand tonnes) is: Ethiopia, 12·8, Israel (Eilat), 1·3; Jordan, 0·2; Kamaran Islands, 0·5; Saudi Arabia, 5·0; Sudan, 1·3; U.A.R., 16·7; Yemen, 2·5; and Federation of South Arabia, 5·0.

The share of Persian Gulf area to the Indian Ocean catch stands on an average at 47,800 tonnes; the country-wise break-up (in thousand tonnes) of which is as follows: Iran, 16·9; Iraq, 1·1; Kuwait, 11·7; Qatar, 0·6; Trucial-Oman, 12·0; Saudi Arabia, 4·0; and Bahrain, 1·5.

The average annual catch from the Bay of Bengal at present is about 7,06,900 tonnes; the country-wise details (in thousand tonnes) is: east coast of India, 212·4;

East Pakistan, 46·6; Burma, 257·0; west coast of Thailand, 23·9; west coast Malaysia, 70·2; Ceylon, 96·5; and Andaman and Nicobar Islands (India), 0·3.

The approximate average annual yield from the Indian Ocean portion Indonesia is 1,75,000 tonnes and that of West Australia is about 12,200 tonnes.

Besides the above, an estimated 1,50,000 tonnes, mostly consisting of tunas a billfishes, are taken from the oceanic fishing in the Indian Ocean.

The above figures indicate that about 75 per cent of the present annual yie comes from the Arabian Sea and Bay of Bengal, which comprises about one-third the total Indian Ocean area. This focuses the present uneven development of fisheri in the various regions of the Indian Ocean. Taking country-wise, India alone accou for nearly 40 per cent of the total annual marine fish yield of the Indian Ocean regio

Detailed species composition of the annual yield is not available for most of th countries in the region. Detailed variety-wise compositions are available for Ceylo India and Pakistan (FAO Yearbook, 1967), and these figures have been direct used in the estimation of the composition of yield of Indian Ocean region. Estima for the whole countries as in South Africa, Malaysia, Australia and Thailand a available, whereas estimates for the countries along the Indian Ocean portion are n available. Shomura *et al.* (1967) gave the data on the composition for the Indian Oc portion of Malaysia, Thailand and Australia. For other countries in the region, t composition has been worked out from the data given in Tables of Section C of FA Yearbook. Because of these limitations, the variety-wise composition for the regi can be given only according to the broad groups adopted by the FAO. The co position of various groups along with the associated percentages is given in Table

TABLE 3. VARIETY-WISE COMPOSITION OF YIELD FROM INDIAN OCEAN AND ASSOCIAT PERCENTAGES

Sl. No.	Groups	Average yield (in 1,000 tonnes)	Percentage
1.	Flounders, halibuts, soles, etc.	9·5	0·44
2.	Cods, hakes, haddocks, etc.	5·5	0·26
3.	Red fishes, basses, congers, etc.	410·9	19·24
4.	Jacks, mullets, etc.	60·7	2·84
5.	Herrings, sardines, anchovies, etc.	591·4	27·69
6.	Tunas, bonitos, skipjacks	228·5	10·70
7.	Mackerels, billfishes, cutlass fishes, etc.	182·7	8·56
8.	Sharks, rays, chimaeras	106·2	4·97
9.	Unsorted and unidentified fishes	203·9	9·55
10.	Crustaceans	265·2	12·42
11.	Molluscs, etc.	70·1	3·28
12.	Sea cucumbers, urchins, etc.	0·9	0·05
	Total	2,135·5	

The group consisting of herrings, sardines, anchovies, etc. contribute 27·69 per cent of the total catch from the Indian Ocean (Table 3). About 60 per cent of the catch of this group is landed in India. They are also landed in substantial quantities in the Persian Gulf area and along the coasts of Federation of South Arabia, Ceylon, Burma and Indonesia. *Sardinella longiceps*, the oil sardine, is the most important single species belonging to this group, and in India it accounts for nearly 70 per cent of the landings of this group.

Next in importance is the group consisting of red fishes, basses, congers, etc. Their landings account for 19·24 per cent of the total yield from the Indian Ocean. This group of fish is landed in varying quantities in almost all countries of the Indian Ocean region. India accounts for the largest share of nearly 45 per cent. Substantial landings also take place in Federation of South Arabia, Muscat-Oman, Pakistan, Burma, Ceylon, Malaysia and Indonesia. In India, out of an average landing of 1,85,000 tonnes, Bombay duck accounts for 77,000 tonnes, silver bellies for 44,000 tonnes, jewfish for 26,000 tonnes, catfishes for 23,000 tonnes, perches for 12,000 tonnes, and eels for 2,000 tonnes.

The third important group in order of landings is crustaceans, which account for 12·42 per cent of the total yield. Out of an average annual landing of about 2,65,000 tonnes, India lands about 91,000 tonnes mostly consisting of shrimps. Substantial landings take place also in Pakistan, Malaysia, Indonesia and Australia.

Tunas, bonitos and skipjacks form the next important group and account for nearly 10·70 per cent of the total yield from the Indian Ocean. More than 60 per cent of these are caught from the highseas by countries outside the Indian Ocean region, notably by Japan and the rest by the countries of the region from the coastal areas. The most important landings take place in Ceylon, Muscat-Oman, Maldive, India and Pakistan.

The group consisting of mackerels, billfishes, etc. account for 8·56 per cent of the total landings. Out of an average catch of 1,83,000 tonnes, India lands on an average 83,000 tonnes, Malaysia 11,000 tonnes, Pakistan 11,000 tonnes and Indonesia 27,000 tonnes. The average composition of the landings in India is Ribbon fish, 40,000 tonnes; Indian mackerel, 33,000 tonnes; seer fish, 10,000 tonnes.

POTENTIAL YIELD (ASSESSED FROM EXPLORATORY SURVEYS)

East African coast (inshore waters)

The maximum sustainable yield from the inshore areas is believed to be small. There are indications that catches from the coastal fisheries of the islands are already reaching or have reached their maximum. Wheeler and Ommanney (1953) regarded the Mauritius inshore fishery as "a closed fishery, confined with unalterable limits and incapable of yielding more than a certain amount of fish, however intensively fished." Likewise, in the Seychelles inshore fishery "there is reason to believe that overfishing of a limited stock has already taken place" (Anon., 1965). According to Moal (1962) the physical features of the coastal shelf limits the development of coastal fishery of Comoro Islands. In Madagascar the broader shelf of the west coast has development potential. Kerr (1966) estimated a 50 per cent increase in production as the maximum possible attainable limit, though according to Shomura *et al.* (1967) a five-fold or more increase is possible. Selwyn and Watson (1962) reported on the great scope for development output of fish from Zanzibar Island. Considering other evidences, Kerr (1966) concluded that fishable resources of Tanzania, as a whole, are not more than 50 per cent higher than the present catch of the two former constituent countries. Rhodes (1966) remarked that the present catch of Kenya cannot be increased beyond 20,000 tonnes. According to Sanchez (1960) the production along Mozambique coast could be doubled or trebled by improving the present fishing methods and research. Considering the various view points, the potential yield from inshore coastal fishery of East African coast has been derived (Table 4).

TABLE 4. POTENTIAL YIELD FROM THE EAST AFRICAN COASTAL FISHERY

Coast	Present catch (in 1,000 tonnes)	Potential catch (in 1,000 tonnes)
South Africa	3·0	6·0
Mozambique	5·8	17·4
Tanzania		
Tanganyika	16·8	40·4
Zanzibar	10·1	
Kenya	6·2	20·0
Mauritius	1·4	1·4
Madagascar	9·8	14·7
Reunion Islands	2·5	2·5
Comoro Island	1·6	1·6
Seychelles	1·5	1·5
	58·7	105·5

Demersal fishery of the offshore banks

There are several large areas of shallow banks in the western Indian Ocean, particularly on an area between Seychelles and Mauritius, also to the north-west of Madagascar (Aldabra Islands) and to the east, almost in the middle of the Indian Ocean (Chagos Archipelago). These areas are largely unfished. They were, however, surveyed in 1948 and 1949 and it was concluded by Wheeler and Ommanney (1953) that there are very large areas where fishing by the simple method of hand-lining is productive on a scale equalling the best efforts of trawlers and drifters on some of the richest grounds in the world. The availability is almost constant throughout the year and the main demersal fish like *Lutianus civis* and *Lethrinus* can be obtained. Rough calculation showed that available fish potential including sharks is between 2 and 3 million tonnes. Kerr (1966), however, is very skeptical if this high reserve can be exploited at present, though he admits that the resource does represent a large reserve of fish for the subregion, and if fishing technology develops enabling its economic exploitation it may be possible eventually to utilize it.

Sardinella fishery

Substantial stock of *Sardinella* exists in Zanzibar and Pemba channels. *S. jussius* and *S. perforata* frequent inshore waters, but *S. sirm* is present only in small numbers in inshore waters. Losse (1963) felt that large quantities of *S. sirm* can be found further out in sea. Only a small quantity is available in other coastal waters. In Kenya not more than 300 tonnes could be caught (Bell and Ochi, 1965). According to Kerr (1966), a potential catch of 5,000 tonnes on present assessment could be expected.

Crustacean fishery

Postel (1965) estimated that the resources of lobster along the East African coast could yield about 5 times their present yield, but no increase is possible from Madagascar stock, which is limited. The total lobster catch could therefore be increased to 3,000 tonnes in the area.

Kerr (1967) concluded that for prawns the maximum sustainable yield for the region would be about 10,000 tonnes.

The break-up of the total potential yield for the area is 31,25,000 tonnes. The break-up (in thousand tonnes) is as follows: Inshore, 105; Banks 3,000; *Sardinella* 5; Crustacea 15.

Arabian Sea coast

French Somaliland and Somalia: The shelf in French Somaliland and Somalie s narrow. The resources here are mainly pelagic. The potential yield from thesa coastal waters will be about 50 per cent more than the present catch, i.e. about 8,000 tonnes (Kerr, 1966).

South Arabian Peninsula: According to Morgan (1966) there is some scope for increased catches of ground fish if suitable gear can be devised to meet the often difficult bottom conditions of the continental shelf off the south Arabian Peninsula, where the shelf averages no more than 8 km in width. Mietle (1967) remarked that the sea of the south Arabian Peninsula could yield annually twice the quantity landed at present, i.e. 70,000 to 1,00,000 tonnes.

Even though there is limited scope for development of demersal fisheries, there are possibilities of significant development of pelagic fisheries in this region. This area is very rich in nutrient salts and plankton due to seasonal upwelling of deep water during the south-west monsoon. According to Schaefer (*vide* Shomura *et al.*, 1967) this area can support a production as high as 10 million tonnes. According to Mietle (1967), the maximum sustainable yield of pelagic fish in the Gulf of Aden is at least 1,50,000 tonnes, consisting of 15,000 to 20,000 tonnes of tuna, 70,000 to 80,000 tonnes of sardines, 20,000 tonnes of king fish and 30,000 tonnes of Indian mackerel. The greatest potentiality for development, however, seems to be in the eastern part of the south Arabian coast and in the Gulf of Oman, an area which could support a sustainable annual yield of about 5,00,000 tonnes of pelagic fish (Kerr, 1966). According to a survey report of FAO/EPTA (Anon., 1963) there does not seem to be shrimp resource in the area, but the area can probably support an annual few thousand tonnes of lobsters.

Thus the potential yield of all types of fishes from this area would seem about 7,50,000 tonnes.

West Pakistan: The present yield from the waters off West Pakistan is 1,17,000 tonnes, of which about 84,000 tonnes are demersal fish. Tiews (196 mated a potential yield of about 2,10,000 tonnes of demersal fish from the sh of West Pakistan. Jones and Banerji (1968) showed that the same area could p support an annual yield of 1,63,000 tonnes of demersal fish, i.e. about 30 hectare of water surface area. A potential yield of about 90,000 tonnes of pel could be taken off annually from the shelf area.

West Coast of India: Jones and Banerji (1968) observed that the shelf area support an annual yield of 5,77,000 tonnes of demersal fish including crustaceans about 10,20,000 tonnes of pelagic fish. The present average annual yield fr shelf area is about 6,50,000 tonnes consisting of 1,80,000 tonnes of demersa 4,70,000 tonnes of pelagic fish.

Laccadive and Maldive Islands: There are also possibilities of development of fisheries in the shelf area off these islands. The total catch at present is of th of 16,000 tonnes, mainly in pelagic fish. Jones and Banerji (1968) stated t annual catch of 7,000 tonnes of demersal and 22,000 tonnes of pelagic fish co harvested from the shelf areas of these island groups. The estimated total po annual yield from the Arabian Sea area is given in Table 5.

TABLE 5. POTENTIAL ANNUAL YIELD FROM THE ARABIAN SEA AREA

	Demersal (including crustaceans)	Pelagic	To
French Somaliland and Somalia	—	—	
Federation of South Arabia, Muscat, Oman	1,00,000	6,50,000	7,
West Pakistan	1,60,000	90,000	2,
India, west coast	5,80,000	10,20,000	16,
Maldives, Laccadives, Chagos, St Paul and New Amsterdam	7,000	23,000	
Total	8,47,000	17,83,000	26,

Red Sea

The present landings in this area are of the order of 44,000 tonnes, p species forming the bulk.

The Red Sea is an almost land-locked basin and the fauna of the basin is to be either completely or partially isolated. Hence, apart from some pelagic the fish stock should be regarded as self-supporting and as such there is not much for development of demersal fishery. However, there seems to be susbstantial scope for development of pelagic fisheries. Nelson and Lee (1962) observed schools of fish of tremendous size in the central and southern parts of the Red Sea. The Greek fishermen who visited these regions have given the pontential catch of 1,40,000 tonnes per month from the Red Sea. The findings of *Atlantis II* of the Woods Hole Oceanographic Institute also support the richness of the Red Sea in fish fauna. But it is also possible that only limited areas of Red Sea, particularly in the south, are rich in fish fauna (Anon., 1962). Nelson and Lee (1962) in their survey of Egyptian waters pointed out that the catch does not seem to be very great in the northern part of the Red Sea, including Gulf of Suez. According to them, there is some evidence that the resources may be over-exploited. There seems to be some potential oyster resources in Gulf of Suez area.

The fishing ground near Port Sudan, where most of the fishing has so far been carried out, does not seem to be productive (Anon., 1958). The best grounds are found outside and near the islands and reefs up to a distance of 60 miles from Port Sudan. Kristjonsson (1956, 1958) observed that, except for some red snappers in some seasons, there is no evidence of abudance of fish in southern Sudan. Reed (1964) found that there are no opportunities for the development of large-scale commercial fisheries in Sudan and the present annual Sudanese catch can at best be increased only to about 3,000 tonnes.

There appear to be some possibilities for increasing the fish catch along Saudi Arabian coast. Exploratory fishing in Saudi Arabian coast indicated the presence of schools of pelagic fish, mainly bonito, and also mackerel and sardines (Anon., 1958). Some relatively productive trawl grounds were also found, but the catch consisted of small fish which are not in great demand. No estimates are, however, available of the potential annual yield from the Saudi Arabian coast.

An excellent shark fishery is now being developed near Karaman Island. There are also reports that Yemen has considerable potential for developing its Red Sea fisheries resources.

Mietle (1967) concluded that the Red Sea as a whole can yield about 1,50,000 tonnes of fish annually, i.e. about 3 times the present yield. According to him the major part would consist of pelagic species such as sardines, tuna, mackerel and sharks. He also assumed that crustacean stocks would yield a few thousand tonnes.

Persian Gulf

This gulf is a shallow basin with a mean depth of about 35 m and a maximum depth of about 150 m. The bottom is of sand and soft mud; the southern part is interspersed with numerous coral reefs. Extensive trawlable grounds exist, particularly near the Iranian coast.

The average annual catch based on 1965–67 data is estimated at about 48,000 tonnes consisting of about 18,000 tonnes of demersal fish, 18,000 tonnes of pelagic and about 12,000 tonnes of shrimps.

Mietle (1967), while discussing the potential yield from the Persian Gulf, concluded that about 30,000 tonnes of demersal fish, 40,000 tonnes of pelagic fish and 25,000 tonnes of crustaceans, totalling 95,000 tonnes, could be obtained as sustained annual yield from the area.

Thus for the western Indian Ocean, excluding the oceanic resources, the annual potential yield would be about 6 million tonnes (Table 6).

TABLE 6. ANNUAL POTENTIAL YIELD FROM THE WESTERN INDIAN OCEAN (IN 1,000 TONNES)

Coast	Demersal	Pelagic	Crustacean	Total
East African coast	105	5	15	125
East African Offshore Bank	3,000	—	—	3,000
Arabian Sea	650	1,790	200	2,640
Red Sea	120	25	5	150
Persian Gulf	30	40	25	95
Total	3,905	1,860	245	6,010

Bay of Bengal

East coast of India: The present average annual production from the east coast of India is about 65,600 tonnes of demersal fish and 1,47,000 tonnes of pelagic fish. Proper exploitation of the shelf area beyond the currently exploited fishing grounds is, however, likely to open up new unexploited grounds of demersal fish. Jones and Banerji (1968) estimated a potential yield of 1,43,000 tonnes of demersal and 6,72,000 tonnes of pelagic fish from the shelf area of the east coast of India.

East Pakistan: East Pakistan has a wide shelf area enriched by the silt-laden discharge of the Ganges river system. The shelf area is practically unexploited at present. Some demersal fish are caught near the inshore waters. Tiews (1966) estimated a potential annual catch of 1,20,000 tonnes of demersal fish from the shelf area of East Pakistan, whereas according to the estimate of Jones and Banerji (1968) the potential annual yield of demersal fish would be 98,000 tonnes and that of pelagic fish 2,50,000 tonnes from the shelf area of East Pakistan.

Burma: The present catch of demersal fish is only 5 kg per hectare of the shelf area. Tiews (1966) estimated a pontetial yield of 3,70,000 tonnes of demersal fish. There are also great potentialities for pelagic fish. Jones and Banerji (1968) estimated a potential annual yield of 7,26,000 tonnes of fish from the shelf area of Burma, consisting of 3,26,000 tonnes of demersal fish and 4,00,000 tonnes of pelagic fish.

West coast of Thailand: The west coast of Thailand has a wide shelf area, the width of the shelf being 64 to 160 km wide. The present catch is only 23,900 tonnes, consisting of about 5,000 tonnes of *Rastrelliger* spp., 8,600 tonnes of sharks and rays, 1,000 tonnes of crustaceans, and the balance in miscellaneous fish. The low production is because the west coast of Thailand is exploited very little at present. Tiews (1966) estimated that this area could support an annual potential yield of about 56,000 tonnes of demersal fish. Jones and Banerji (1968) assessed an annual sustainable yield of 58,000 tonnes of demersal fish and 20,000 tonnes of pelagic fish like mackerel, *Decapterus*, *Stolephorus* and wolf herrings. According to Shomura *et al.* (1967) the area is suitable for culture of mussels, prawns and mullets.

West coast of Malaysia: Just like the west coast of Thailand, the west coast of Malaysia has a wide shelf area which is very little exploited. The production of demersal fish could be increased substantially through the development and expansion of commercial trawl fisheries in the shelf area. According to Tiews (1966) the shelf area of Malaysia could support an annual potential yield of 6,00,000 tonnes of demersal fish. The present annual production from the west coast of Malaysia, which is virtually untapped, is about 70,000 tonnes consisting of about 35,000 tonnes of pelagic fish, 15,000 tonnes of crustaceans and 19,000 tonnes of molluscs. No estimates are available regarding the annual potential yield of pelagic fish but, since the area is under-fished, it would be reasonable to assume that the potential yield of pelagic fish could be increased by 2 to 3 times the present production.

Ceylon: The present annual production of marine fish from Ceylon waters is about 97,000 tonnes, of which about 34,000 tonnes consist of demersal fish. Ceylon has a shelf area of about 25,000 sq km, which is not exploited at present to the maximum. Tiews (1966) furnished an estimate of 60,000 tonnes of demersal yield for the whole of Ceylon. Jones and Banerji (1968) observed that an annual sustainable yield of 52,000 tonnes of demersal and 90,000 tonnes of pelagic fish could be obtained through rational exploitation of the shelf area.

Andaman and Nicobar Islands: The commercial fishing is carried out only from Port Blair, and it amounts to 300 tonnes consisting of 100 tonnes of demersal and 200 tonnes of pelagic fish. In the rest of the island regions, only subsistence fishing is carried out by the local people. These island groups have a continental shelf of 16,000 sq km. Jones and Banerji (1968) gave a minimal estimate of 4,000 tonnes of demersal and 8,000 tonnes of pelagic fish.

The country-wise break-up of the total potential yield from the Bay of Bengal region is shown in Table 7.

TABLE 7. TOTAL POTENTIAL YIELD FROM THE BAY OF BENGAL REGION (IN 1,000 TONNES)

Coast	Demersal	Pelagic	Total
India (east coast)	143	672	815
East Pakistan	98	250	348
Burma	326	400	726
Thailand (west coast)	58	20	78
Malaysia (west coast)	600	100	700
Ceylon	52	90	142
Andaman and Nicobar Islands	4	8	12
Total	1,281	1,540	2,821

Indonesia and Australia

West coast of Indonesia: Shomura *et al.* (1967) assessed the annual production of marine fish in 1963 from west coast of Indonesia at about 1,15,000 tonnes. Taking the average annual total fish production based on figures of 1965 and 1966 (Anon., 1967) and substracting the average freshwater fish production and taking 25 per cent of that to be production from the west coast of Indonesia, the present estimated production is of the order of 1,75,000 tonnes. No information is available on the composition of the catch, but according to Shomura *et al.* (1967) the fishery resources are similar to that of North Australia, Malaysia, Thailand and Burma. Although estimates of potential annual yield are not available, this area is very rich and upwellings are found south of Sunda Islands. Hence, it may be assumed that the potential yield would be at last two times the present yield, i.e. 3,50,000 tonnes. The only area suitable for trawling lies off the western end of Sumatra. The potential for the greatest increase in yield probably lies in the area along the southern coast of Java, where intense upwelling occurs. There is a fishery for sardines in the Straits east of Java. The catch from this area may be from the fringe of a large sardine resource of the south. If the conditions are similar to other areas of upwelling in the Indian Ocean, a large resource of clupeoids could be expected.

West Australia: The continental shelf is less than 65 km in width in the south-western part of the continent. Northwards the shelf becomes wider, and in the north-west it exceeds 320 km in width. The present annual yield is about 12,000 tonnes including about 7,500 tonnes of crayfish. The Australian scientists estimated that the optimum yield of crayfish in the west Australian stock to be about 7·3±0·9 thousand tonnes. Hence, no further increase in crayfish landings seems possible. But possibilities of development exist in the north-western coast of Australia with a very wide trawlable shelf. The area is very poorly known. Recent surveys show that potential for prawns is good. Substantial catches of bottom fishes of good quality were made during a Japanese bottom trawling survey (Masuda *et al.*, 1964). These indicate prospects of increasing the present meagre yield of 12,000 tonnes and with the present knowledge of the area of potential yield of 50,000 tonnes does not seem to be an unreasonable estimate.

The area-wise break-up of the potential annual yield for the eastern Indian Ocean is given in Table 8.

TABLE 8. POTENTIAL ANNUAL YIELD FOR THE EASTERN INDIAN OCEAN (IN 1,000 TONNES)

	Demersal	Pelagic	Total
Bay of Bengal	1,281	1,540	2,821
Indonesia	90	260	350
Australia	30	20	50
Total	1,401	1,820	3,221

Oceanic fishery: The oceanic fishery consists of various types of tunas and bill-fishes. The estimated catch taken from the Indian Ocean is about 1,50,000 tonnes, comprising yellowfin tuna, big-eyed tuna, albacore, bluefin tuna, marlins, skipjacks and sauries.

The yellowfin tuna has a wide distribution but the maximum concentration is in the equatorial waters. The fish is virtually absent in the northern portions of Arabian Sea and Bay of Bengal. According to Mimura (1958) the average size of yellowfin tuna taken by long-line has decreased since the commencement of the fishery. Hayashi (1966) came to the conclusion that the present fishing intensity may be very near the maximum level that could be employed for getting an optimum yield of this species.

Big-eyed tuna, distributed almost throughout the Indian Ocean, are mostly concentrated between the equator and 10°S Lat. in the eastern Indian Ocean and between equator and 10°N Lat. in the western Indian Ocean. Like the yellowfin, the species is again absent in the northern portions of Arabian Sea and Bay of Bengal. Suda (1966) remarked that the coefficient of natural mortality M is 0·6 and that of fishing mortality F varies from 0·3 to 0·6. The maximum sustainable yield would be achieved according to him at $F=0\cdot7$. Sakamoto (1966) by analysing catch and effort data came to the conclusion that the big-eyed tuna population has somewhat declined in the Indian Ocean.

The greatest concentration of albacore is in the south-west region of the Indian Ocean, though the species is available throughout the Indian Ocean south of the equator, it being practically absent north of the equator. The relative abundance of albacore has gradually decreased since 1953, and in 1963 it was about half that of the earlier years.

The bluefin tuna has a scattered distribution south of the equator. It is highly abundant in the south of Indonesia and in the north-west, west and south-west of Australia. It is also fairly abundant off South Africa during southern winter (Talbot and Penrith, 1963). The Australian catch of bluefin tuna has increased considerably, primarily due to increase in Australian pole-and-line fishery. The relative abundance has declined to about one-third that of earlier years. According to Hynd *et al.* (1966), the total catch of bluefin tuna represents about 10 per cent of the population off South Australia.

Excepting the northern portions of Arabian Sea and Bay of Bengal, marlins are available throughout the Indian Ocean. Striped marlins are abundant in the Bay of Bengal and south-west coast of India, and blue marlins in greatest abundance in south of regions of abundance of striped marlin. The highest concentration of black marlins are in the eastern Indian Ocean—west of Indonesia and north-west Australia. Changes in abundance have not been computed.

The skipjack tuna is exploited very little at present. The main fisheries at present are the pole-and-line fishery of Minicoy and the small trolling fishery of Ceylon. According to Chapman (1962) there is no reason to suspect that they are not as abundant in the Indian Ocean as compared to the Pacific. The meagre production of skipjack at present is becaue they are not caught. Its yield from the Indian Ocean can be increased many-fold from its present estimated catch of 5,000 tonnes.

Similarly, Saury is encountered throughout the wide area of the southern Indian Ocean. Saury might also represent a large latent resource.

The assessment made by Shomura *et al.* (1967) showed that, although a numb of tuna species in the Indian Ocean are being taken by long-line gear at levels whic suggest little or no potential increase, the skipjack tuna and Saury are very mu under-utilized resources.

In terms of production per unit area of water, the yield from the Indian Oce is about a third of that from the Pacific Ocean, where maximum exploitation has no yet been attained. It is therefore reasonable to assume that the Indian Ocean ca be exploited at least to the level of present-day fishing in the Pacific Ocean to give a annual yield of 4,50,000 tonnes of oceanic pelagic fish like tunas.

Thus, combining the various estimates of potential yield available from differen regions based on exploratory surveys and various other considerations, it is seen th the Indian Ocean can probably support an annual potential yield of 10–11 millio tonnes of marine fish.

COMPOSITION OF POTENTIAL INCREASE

The total catch from the western Indian Ocean at present is about 10,91,40 tonnes. The potential yield from the area was computed at 60,10,000 tonnes consis ting of about 39,05,000 tonnes of demersal fish, 2,45,000 tonnes of crustaceans an 18,60,000 tonnes of pelagic fish. The potential increase possible is thus abou 49,20,000 tonnes per year. The regional distribution of this is shown in Table 9.

TABLE 9. REGIONAL DISTRIBUTION OF POTENTIAL INCREASE IN WESTERN INDIAN OCEA (IN 1,000 TONNES)

Region	Demersal (including crustaceans)	Pelagic	Total
Red Sea	10	90	100
African coast	25	40	65
Offshore banks of Africa	3,000	—	3,000
Arabian Sea	533	1,175	1,708
Persian Gulf	25	22	47
Total	3,593	1,327	4,920

According to Mietle (1967) the potential annual yield from the Red Sea area wi be about 1,50,000 tonnes as against the present annual catch of 45,000 tonnes. Th composition of the potential increase (in tonnes) will be: Sardines, 20,000; mackere 25,000; tuna and bonitos, 40,000; sharks, 5,000; perches, 5,000; crustaceans 5,00 and other species 5,000.

The flatfish stocks of the Agulhas Bank are probably being exploited to th maximum. But the fisheries of pilchard (*Sardinops*) and rocky bottom fishes of th shelf of South Africa could be developed further. Similarly, the *Sardinella* and othe coastal pelagic fisheries could be developed off the coasts of Mozambique, Tanzania and Kenya. The outlook of development for prawn and lobster fisheries along these coasts is also bright. The development of north-west coast fisheries of Madagascar is likely to fetch increased yield of *Sardinella* and associated species. Exploitation of offshore regions of Zanzibar and East Africa might yield additional quantities of crustaceans and *Sardinella sirm.* The increased yield from these development measures might yield 40,000 tonnes pilchard and sardines and 25,000 tonnes crustaceans. But the maximum potential yield might come from exploitation of the offshore banks between Seychelles and Mauritius, and would consist of fishes like *Lutiannus civis*, *Lethrinus* and sharks.

The Arabian Sea could also support a potential increase of 17,08,000 tonnes of fish above its present annual yield. The shelf area of South Arabian Peninsula and Oman could yield an additional 50,000 tonnes of ground fish and 5,50,000 tonnes of pelagic fish, the likely composition of which (in tonnes) would be: tuna, 60,000; sardines, 3,10,000; kingfish, 60,000; and mackerel, 1,20,000.

Tiews (1966) and Jones and Banerji (1968) observed that the major resources of bottom fish on the coasts of West Pakistan and west coast of India remain virtually untapped. According to the latter the commercial exploitation of the shelf area of this region could yield an additional quantity of nearly 4,75,000 tonnes of demersal fish including shrimps and lobsters. Although it is difficult to give a detailed composition of this additional yield, some idea could be obtained from the exploratory fishing carried out in India. According to Jones and Banerji (1968) the demersal catch from the Maharashtra and Gujarat area consisted of elasmobranchs, eels, catfishes, perches, red mullets, polynemids, sciaenids, *Lactarius*, pomfrets, soles, prawns and other miscellaneous catch. The catch as well as catch per unit effort from both inshore and offshore fisheries definitely declined in case of *Polynemus indicus* (*dara*), *Otolithoides brunnes* (*koth*) and eels. In case of most other groups, no such declining trends were noticed, suggesting that most of these demersal species were under-exploited. Though, in general, the catch rate declined beyond 40 m in case of certain categories of fish like small sciaenids, eels and elasmobranchs, the catch rate increased beyond 40 m belt and these areas remain practically unfished at present. In the shelf area of Mysore and Goa no special effort was made to fish for demersal fishes, the fishing at present being restricted to coastal waters. Only recently a few small motorized boats have started operating for the exploitation of prawns. Exploratory shrimp trawling done in Karwar has showed excellent catch rate of 192 kg per hour. Very little prawns were obtained. *Opisthopterus tardoore* and *Leiognathus* formed more than 50 per cent of the catches along with sizable catch of *Lactarius*, sciaenids and elasmobranchs. Since none of these species are now being exploited to any degree in the coastal waters at present, they form potential resources to be exploited. The shelf area of Kerala is being exploited up to 40–50 m. The main groups of fish are prawns, elasmobranchs, catfishes, sciaenids, sole and other miscellaneous fish. Prawns form about 45 per cent of the demersal catch. The catch per unit effort and the mean size of prawn in the commercial catch show decline, and the catch also do not show noticeable increase. It probably indicates that the prawn stocks within the 50 m belt are being exploited to the maximum. The other groups seem to be very much under-exploited. Further, the area between 50 and 200 m remains practically unexploited. Recently, some new prawn and lobster beds have been discovered in the deep water with promising prospects. Rao (1969) gave detailed account of the results of exploratory surveys in the shelf area of India.

The present yield of pelagic fisheries from the shelf area of west coast of India is about 4,70,000 tonnes. Oil sardine, Bombay duck and mackerel form about 70 per cent of the total pelagic catch. The fisheries of oil sardine and mackerel are characterized by their wide annual fluctuations. The prevailing view is that these fluctuations are caused by variations in availability of the stocks due to the severely restricted fishing range at present. The annual catch of Bombay duck has declined somewhat during the last decade. The fishing is by fixed bag net, and hence it is possible that the catch depends on availability. The species is neritic-pelagic having a long migration circuit still unknown. Hence it is likely that the present catch of all these three species is much lower than the potential yield. The stocks of other small pelagic groups are not exploited to the full and some potential increase from these stocks seems possible.

The total catch from the eastern Indian Ocean at present is about 8,95,000 tonnes and the potential yield has been estimated in the preceding section at 32,21,000 tonnes consisting of 14,00,000 tonnes of demersal fish and 18,20,000 tonnes of pelagic fish. The region-wise break-up of the potential increase is given in Table 10.

TABLE 10. REGIONAL DISTRIBUTION OF POTENTIAL INCREASE (EASTERN INDIAN OCEAN) (IN 1,000 TONNES)

Region	Demersal (including crustaceans)	Pelagic	Total
India (east coast)	77	525	602
East Pakistan	62	238	300
Burma	198	272	470
Thailand (west coast)	43	11	54
Malaysia (west coast)	560	70	630
Ceylon	18	27	45
Andaman and Nicobar Islands	4	8	12
Indonesia (east coast)	45	130	175
Australia (west coast)	22	16	38
Total	1,029	1,297	2,326

At present, along the east coast of India the demersal fishery is exploited in inshore waters with shore-seines and boat-seines. Experimental fishing done at Tuticorin, Mandapam and Waltair shows good catch rates, though not as high as in the west coast. Experimental fishing off Tuticorin in south-east India showed tha sciaenids, *Leiognathus*, elasmobranchs, prawns, perches, polynemids and miscellaneou fishes form the demersal fishery. Exploratory fishing around Mandapam showed that the catch consisted of about 90 per cent of *Leiognathus*, the rest being *Lactarius*, prawns, pomfrets, catfish and sharks. The catch obtained from exploratory fishing around Waltair composed of elasmobranchs, catfishes and others.

The wide shelf area of East Pakistan, Burma, Thailand and Malaysia would yield a substantial amount of demersal fish, the composition of which is difficult to predict. The only areas which are shallow enough for trawling occur off the western end of Sumatra, the north-west coast of Australia and some sections of southern coast of west Australia.

The pelagic resources of the Bay of Bengal might consist of fishes like mackerel, *Decapterus*, *Stolephorus*, wolf herrings and lesser sardines. The stock of each of these might not be large but there might be a large number of small stocks of many species.

According to Shomura *et al.* (1967) mussel and fish farming have tremendous possibilities in the delta area of Bay of Bengal and other mangrove estuarine areas of Burma, Thailand and Malaysia.

ESTIMATION OF POTENTIAL YIELD FROM VARIOUS TROPHIC LEVELS

Schaefer (1965) estimated the potential productivity of the sea by calculating the harvestable crop from the net rate of photosynthesis of organic matter and its subsequent transfer through the food web. The input of any trophic level is taken as the predation loss from the next lower trophic level. By taking a suitable ecological efficiency factor, the maximum sustainable rate of yield (predation loss) from a trophic level is obtained. According to Schaefer (1965) "the effective ecological efficiency may be higher than 10 per cent due to recycling of organic matter, 15 per cent would not seem an unreasonable guess and 20 per cent should be possible". It is not always possible to assign a proper trophic level to many organisms. Pelagic fishes like sardines, anchovies and herring which feed on phytoplankton and a mixture of phyto- and zooplankton are considered as one and a half steps above phytoplankton, while the other types of fishes especially tunas are taken from higher trophic levels. The carbon production of the western and eastern Indian Ocean has been separately traced through the various trophic levels (Tables 11, 12).

TABLE 11. ESTIMATES OF POTENTIAL YIELDS AT VARIOUS TROPHIC LEVELS (ANNUAL), WESTERN INDIAN OCEAN

Trophic level	Ecological efficiency factor					
	10%		15%		20%	
	Carbon	Total wt.	Carbon	Total wt.	Carbon	Total wt.
) Phytoplankton (net production)	$2 \cdot 3 \times 10^9$	—	$2 \cdot 3 \times 10^9$	—	$2 \cdot 3 \times 10^9$	—
) Herbivores	$2 \cdot 3 \times 10^8$	$2 \cdot 3 \times 10^9$	$3 \cdot 3 \times 10^8$	$3 \cdot 3 \times 10^9$	$4 \cdot 6 \times 10^8$	$4 \cdot 6 \times 10^9$
) 1st stage carnivores	$2 \cdot 3 \times 10^7$	$2 \cdot 3 \times 10^8$	$5 \cdot 0 \times 10^7$	$5 \cdot 0 \times 10^8$	$9 \cdot 2 \times 10^7$	$9 \cdot 2 \times 10^8$
2nd stage carnivores	$2 \cdot 3 \times 10^6$	$2 \cdot 3 \times 10^7$	$7 \cdot 4 \times 10^6$	$7 \cdot 4 \times 10^7$	$17 \cdot 6 \times 10^6$	$17 \cdot 6 \times 10^7$
3rd stage carnivores	$2 \cdot 3 \times 10^5$	$2 \cdot 3 \times 10^6$	$11 \cdot \times 10^5$	11×10^6	$35 \cdot 2 \times 10^5$	$35 \cdot 2 \times 10^6$

10 per cent efficiency and $3 \cdot 3 \times 10^9$ and $2 \cdot 4 \times 10^9$ tonnes at 15 per cent efficiency for the two halves, respectively. This estimate is for plankton composed purely of herbivores. Since the zooplankton is composed of herbivores and first-stage carnivores, the estimates of biomass based on zooplankton data would definitely be of lower order of magnitude than the theoretical estimates derived from carbon production.

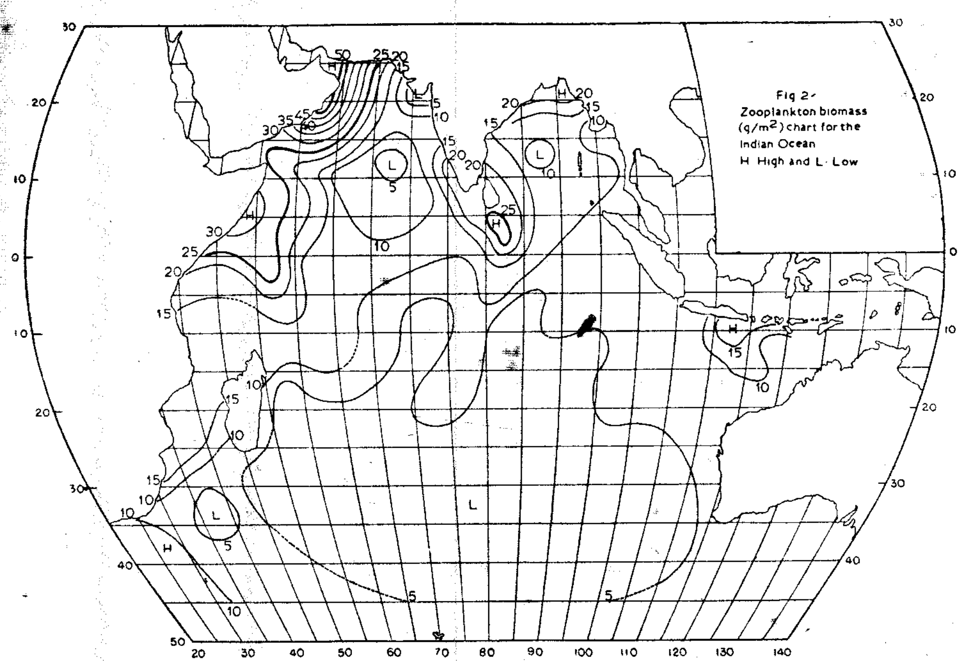

Fig. 2.

The potential fish biomass based on the estimated zooplankton biomass is computed at 18 million tonnes from the western half and 11 million tonnes from the eastern half at 10 per cent efficiency. At 15 per cent efficiency the estimates would be 28 million from the western half and 17 million tonnes from the eastern half. These estimates of fish biomass are also likely to be underestimates, since they are based on samples taken mostly from oceanic regions during the IIOE.

CONCLUSIONS

The relative productivity in the Indian Ocean as a whole is in no way less than that of the rest of the world oceans. At the same time pockets of high productivity occur with rates higher than anywhere else in the world. With an annual organic net production of $3 \cdot 9 \times 10^9$ tonnes for an area of 51×10^6 sq km, it is approximately one-fifth of the world oceanic production, which is estimted at $1 \cdot 9 \times 10^{10}$ tonnes. The Indian Ocean should therefore logically account for one-fifth of the world production of fish also, provided other conditions are favourable. A perusal of the yield raito of the present catch of fish from the Indian Ocean and the Atlantic and Pacific Oceans reveals that the rate for the Indian Ocean is only 0·00 cent while that of the Atlantic is 0·04 per cent and Pacific 0·03 per Accordingly, the possible catch should be of the order of 11 to 12 million at the present level of world fishing to bring it at par with the rest of the world The results of exploratory surveys and the estimate of the potential catch also that the Indian Ocean can possibly provide an annual yield of 10–11 tonnes of fish.

In most of the countries bordering the Indian Ocean, the technological dev ment has not yet attained the stage to provide the facilities for fishing in distant wa Hence the maximum utilization of the resources available on the continental she and banks should form the mainstay at the present stage. From the rates of or productivity observed in the coastal and near-shore regions, the annual net pro tion is found to be of the order of 560×10^6 tonnes of carbon for an area of 3·1 mill sq km. In eutrophic coastal areas where 0·2 to 0·3 per cent of the carbon is as fish, a possible yield of 11 million tonnes could be taken if the resources are utilized. This excludes the oceanic fisheries consisting of tunas, billfishes, etc., present yield of which is about 1,50,000 tonnes. In terms of production per area of water the yield from the Indian Ocean from these resources is only a thi from that of the Pacific Ocean, where itself the maximum exploitation has not been attained.

The theoretical estimates using the method followed by Schaefer (1965) pl the fish biomass for the entire Indian Ocean at 10 per cent efficiency at 39 milli tonnes, and at 15 per cent efficiency at 128 million tonnes if the harvest is taken step 3. If it is assumed that half the harvest is taken at step 2 and half at step 3, biomass will be 214 and 494 million tonnes at 10 and 15 per cent efficiencies, respe tively. Schaefer's estimates of fish biomass at 15 per cent efficiency for the wor oceans are 640×10^6 tonnes if the harvest is taken at step 3, and $2{,}420 \times 10^6$ tonn if half the harvest is taken at step 2 and half at step 3. According to him, abo 200 million tonnes can be taken as the potential yield, i.e. 30 per cent of the form or about 8 per cent of the latter estimates of fish biomass, due to diffuse distributi of fish, economic inability to harvest and loss through predators. Thus, for t Indian Ocean the potential yield derived from the present estimates would be betwe 39 and 40 million tonnes. However, at the present level of world exploitation, whi is only about 27 per cent of the projected potential yield of 200 million tonnes, t estimated yield from the Indian Ocean will be about 11 million tonnes.

SUMMARY

The paper gives an account of primary production and zooplankton biom in the Indian Ocean along with a discussion on the present status and future scope increased exploitation of the fisheries potential.

The part of the Indian Ocean dealt with is between 20° and 120° E longitu and from the Asian landmass to 45°S latitude, comprising an area of 51 million sq or roughly two-thirds of the Indian Ocean.

The annual net organic production for this area is estimated to be 3·9× tonnes, which is about one-fifth of the world oceanic production. The contin

shelf with an area of 3·1 million sq km accounts for one-seventh of the total production in the Indian Ocean. The zooplankton biomass is estimated to be $5 \cdot 19 \times 10^8$ tonnes

Theoretical estimates of the fish biomass in the Indian Ocean have been made, tracing the carbon through various trophic levels. The potential harvest from the Indian Ocean has been computed at 39–40 million tonnes.

The yield ratio of carbon production as well as the estimated potential yield derived from the results of exploratory surveys indicate that, at the present level of world exploitation, the Indian Ocean can possibly support an annual sustainable yield of 11 million tonnes of fish.

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PRIMARY PRODUCTIVITY OF SOME CORAL REEFS IN THE INDIAN SEAS

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ABSTRACT

Primary productivity of coral reefs, in Manauli Island (Gulf of Mannar), Minicoy (Laccadive Sea) and Andaman Islands (Bay of Bengal) was estimated by the diurnal changes of oxygen in the sea water flowing over the reefs. There was a strong unidirectional flow due to trade winds in the first region whereas in the other two regions there was only tidal flow. However, there was measurable variation in all the places between the upstream and downstream measurements of oxygen values and these variations have been graphically integrated in order to obtain the primary productivity.

Manauli and Minicoy reefs are autotrophic with annual net production of 2500 gC/m^2 and 3000 gC/m^2 respectively. The production of the reef near Port Blair, in Andaman Sea is 1200 gC/m^2/year which does not meet the respiratory requirements of the organisms and hence it is not self supporting. The reasons for this difference are briefly discussed.

INTRODUCTION

The warm tropical seas where the coral reefs occur, vary much in organic productivity. In clear oceanic waters where 1% light penetration reaches over 100 metres the rate of production normally does not exceed 0.01 to 0.03 gC/m^2/day, whereas in the shallow waters where there is constant replenishment of nutrients from the bottom the rate exceeds 1 to 2 gC/m^2/day. On the other hand the rate of production on a coral reef is far higher than that of any other marine environment excepting probably turtle grass beds. The gross productivity on a typical coral reef is of the order of 8 to 12 gC/m^2/day (*cf.* Kohn and Helfrich, 1957; Gordon and Kelly, 1962). The highest value recorded for the sea is from the western Arabian Sea—6.4 gC/m^2/day (Ryther *et al.*, 1966) and for a turtle grass bed—12.74 gC/m^2/day (Odum, 1956).

The symbiotic zooxanthellae (*Symbiodinium*) and the boring and attached algae occurring in the coral head contribute the major share of the high organic productivity that is observed over the reefs. The rich assemblage of incidental flora comprising several algal species and eel grass also sometimes form important producers over coral beds. However, all organic matter that is produced is not added to the environment as a good part or even the whole may be utilised by the reef community for their respiration during day and night, while production takes place only during day. Hence based on the photosynthesis: respiration ratio, reefs are classified as autotrophic ($P/R =>1$) or heterotrophic ($P/R=<1$). These investigations which cover three far-flung reefs of the Indian seas were aimed at studying the relative productivity of the reefs situated in different types of environments.

Location and Description of the Reefs

Manauli Reef

This reef is situated in the Gulf of Mannar about 6 km away from the mainland. There is a string of islands here, of which Manauli is the smallest. The northern and northeastern sides are covered by a fringing reef which is mostly made of dead corals. The reef is about 100 metres wide in most parts and is broken with intermittent sandy areas. It is about 500 metres away from the sandy shore of the Island. Towards the eastern side of the reef there is a dominance of *Eachinopora lamellosa* and *Montipora foliosa* both of which cut large platforms 2 to 3 metres across. At the central part the dominant fauna comprises *Favites abdita, Favia pallida, Porites* spp., *Acropora indica, A. surculosa, A. erythraea, A. hyacinthus* etc. The western side of the reef possesses *Acropora nobilis* which covers considerably large areas. But *Favites abdita Favia pallida* and *Acropora* spp., occur all over the reef. Alcyonarians are rare. The large quantities of dead *Porites* on the reef is a clear indication that the reef is dying out rather than developing. Near the shore hermit crabs, gastropods especially *Cerithedia fluviatilis* are abundant. *Holothuria atra* and *H. scabra* are commonly met, with plenty of decapods.

The area selected for the present observations was at the middle part of the reef where there is a rich growth of *Acropora indica, A. erythraea, A. hyacinthus, A. surculosa, Favites abdita, Favia pallida* and some alcyonarians. Two 24-hour studies were carried out on this shoal, the first one being essentially a trial run.

Minicoy Reef

Minicoy (= Minikoi) is at lat. 8°15' N, and long. 73°E. It is more or less oval-shaped and forms the southernmost atoll of the Laccadive Archipelago. The length of the atoll is about 8 km with a maximum width of approximately 4.5 km. The present studies were carried out on a lagoon shoal of this atoll. The shoal is situated at the northeastern end of the atoll opposite to the Mau-Rabu Point and is about 600 metres in length and 40 to 60 metres wide. It is unbroken and mostly made of huge colonies of *Goniastrea retiformis*, with level tops, the sides of which harbour large colonies of *Platygyra lamellina, Favia pallida, Porites* spp., *Diploastrea heliopora* and *Lobophylla corymbosa*. Ramose forms are not abundant there, though rarely *Acropora* spp., and *Pocillopora* *damicornis* are met with. The lagoon between the shore and the shoal is about a metre deep at low tides and about 100 metres wide, the bottom being sandy with dead and broken pieces of corals. The depth, outer to the shoals suddenly increases to 2-3 metres. The top of the shoal gets partly exposed at receding tides. This shoal is the largest unbroken one observed in the lagoon and is comparable to the small 'fringing reefs' met around the islands of Gulf of Mannar around Mandapam.

One 24-hour observation was carried out on this shoal, since such a study could not be carried out on the atoll reef proper due to the limited facilities we had at our disposal and highly fluctuating weather conditions that prevailed. More than 95% of the surface of this shoal is covered by *Goniastrea retiformis.*

The observation was carried out in the first week of April 1968. The mean atmospheric temperature at noon was 32°C and the surface temperature fluctuated from 30 to 31.5 °C. Salinity was 34.73 ‰. The wind direction was southwest to southerly and was blowing at a velocity of 4 to 6 knots with inter-mittent lull (data from the meteorological observatory, Minicoy). The flow of lagoon water over the shoal from the outer side of the shoal towards the shore was often very slow and was influenced by the rising tide. So we could not get a certain steady current throughout the 24-hour period of observation. The Mini-coy lagoon is comparatively shallow with coral shoals towards the northern sector and the western side, whereas the central part is covered by sand flat devoid of any coral growth. The lagoon reef extending from Tunda point to Neru-Magu channel is with a flat boulder zone and on outer slope and the reef gets exposed at low tide. The atoll reef towards the northern end of the atoll remains always submerged. The lagoon water may be regarded as having a high content of oxygen, chiefly due to the shoals and plenty of sea grass (*Cymodocea*) on the sand flat and the regions near to the shore. Two stations were fixed—one inner and other outer to the shoal—the distance between the two being 57 metres.

Andaman Reef

The seas surrounding the Andaman and Nicobar group of islands have a luxuriant growth of coral reefs of the fringing type. Most of them occur at a depth of 5 to 7 metres. Though occasional observations and productivity mea-surements were carried out at a number of points along the shipping route and Nancowrie Harbour, 24-hour observations were conducted only at Preseverance Point near Port Blair, where the construction of a light house was in progress. The dominant species of corals occurring were *Acropora assimilis, A.? syringodes, A. squamosa, Pocillopora damicornis,* several *Faviids* and *Porites* spp.

The flow of water was very sluggish over the reef which was at 6 metres depth on the average. The florescein dye dispersed considerably before moving some distance. Hence observations were taken at two points—one over the reef and another outside the influence of the reef area which was 30 metres away.

of 5.64 ml/1. In this run the distance between the observation points was 200 metres and the average velocity of the current 20 cms/second. As the major part of the flow was over *Cymodocea* beds occurring in the lagoon with a sizable population of sponges, holothurians and crabs, this series was not used for the computation of productivity which would not reflect the true conditions over the coral reef. The gas transfer coefficient (K) was calculated using the formula of Odum (1965). The value of K during this run was found to be 7.5×10^6 ml O_2/m^2/month/atmosphere. The values available for the oceans are those for the Gulf of Maine where the values were 13×10^6 ml O_2/m^2/month/atmosphere in winter and 2.8×10^6 ml O_2/m^2/month/atmosphere in summer (Redfield, 1948) and 3.3×10^6 ml O_2 m^2/month/atmosphere for a Hawaiian reef (Kohn and Helfrich, 1957). During the second run on the Manauli reef the temperature of water was higher by 2° and there was drop in K value to 1.3×10^6 ml O_2/m^2/month/atmosphere indicating that the relationship with temperature is an inverse one.

The mean rate of change of oxygen concentration in millilitres per centimetre of reef normal to the current is given by the formula:

mean depth (cm) X velocity (cm/sec) X mean change in oxygen between stations (ml / cm³) = mean change in oxygen over reef (ml/cm/sec).

Figure 1 shows the trend of oxygen concenration at two stations in the direction of the flow over Manauli, Minicoy and Andaman reefs respectively. Figure 2 represents the oxygen production and consumption curves for the respective stations. Based on graphical integration, production and consumption have been computed, which are further converted into their carbon equivalents. Table 1 gives the values corrected for 100 metre stretch of the reef along one centimetre width.

TABLE 1. *Oxygen production and consumption in ml O_2/cm on Manauli, Minicoy and Andaman reefs.*

Date	Reef	production	consumption
5-3-68	Manauli	13,680	600
2-4-68	Minicoy	16,770	200
24-4-68	Andamans	7,320	32,100

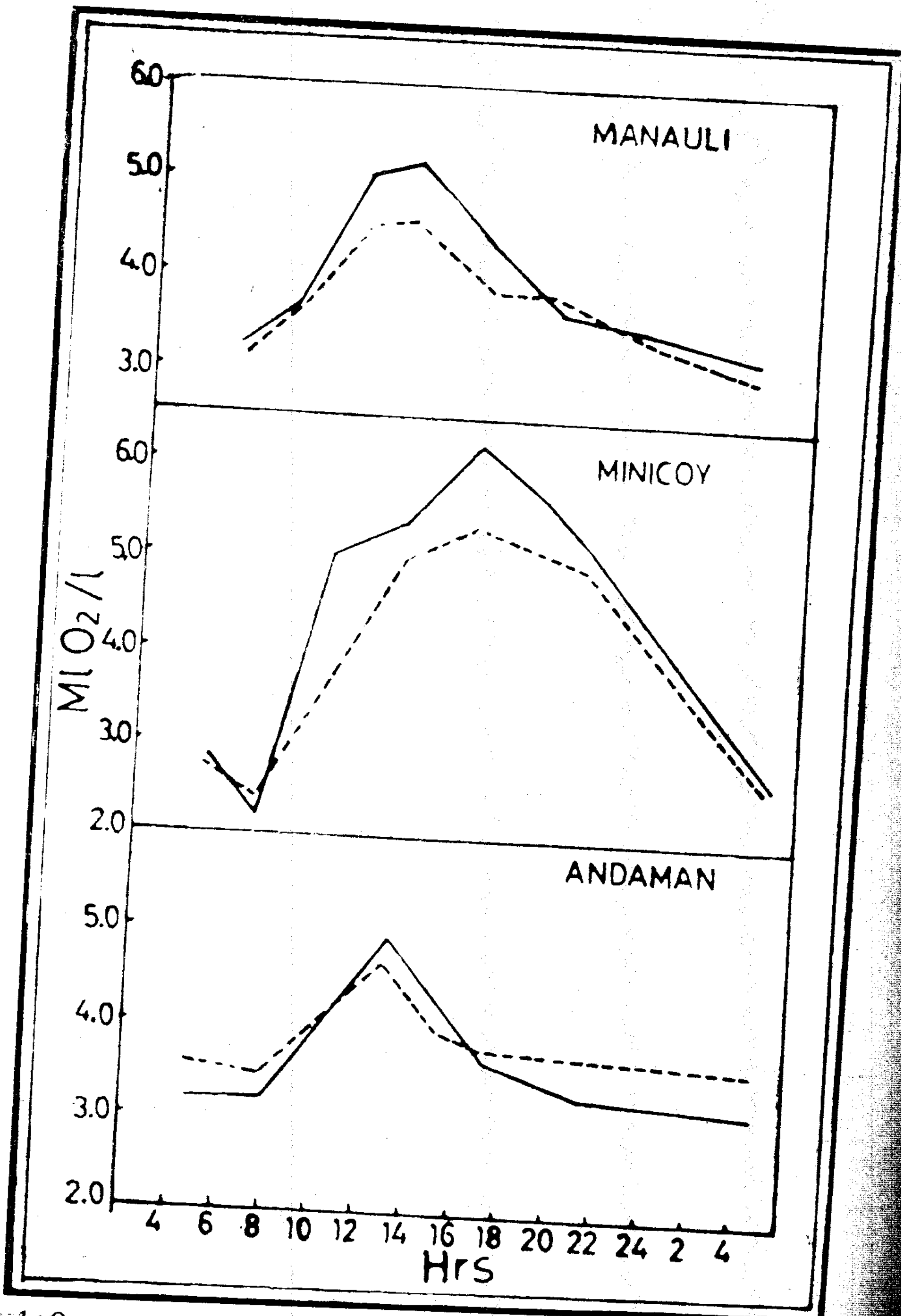

FIG. 1. Oxygen concentration at two stations over the reefs at Manauli, Minicoy and Andamans

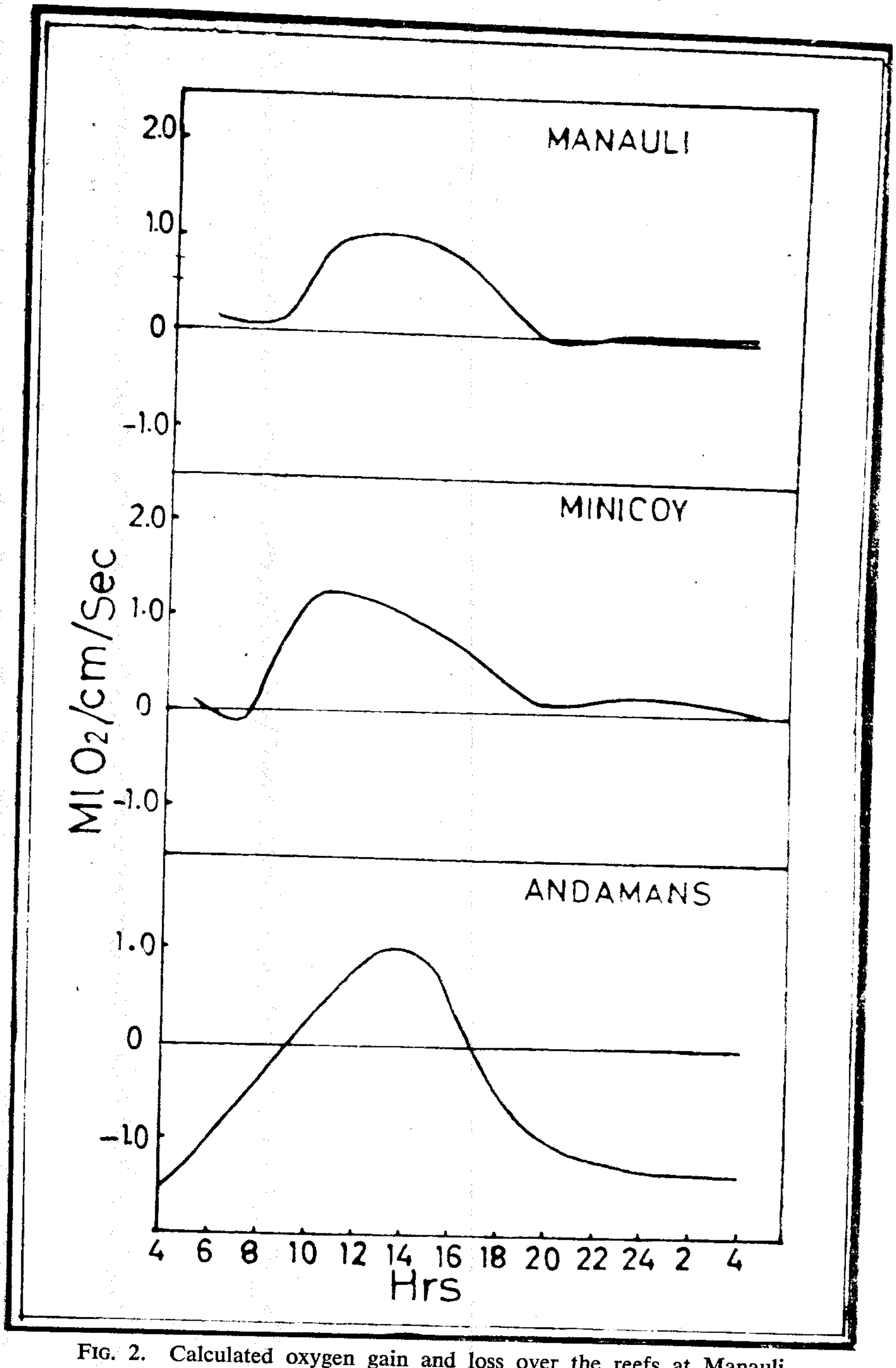

FIG. 2. Calculated oxygen gain and loss over the reefs at Manauli, Minicoy and Andamans.

Converted into carbon equivalents the productivity will be 7.3 gC/m^2/day over Manauli reef and 9.1 gC/m^2/day over Minicoy reef. Both are autotrophic reefs with production exceeding consumption. On the other hand in Andamans (Perseverence Point, North Bay, Port Blair) the production of carbon amounts only 3.9 gC/m^2/day which does not meet the respiratory requirement of the reef organisms. It is an instance of a reef which is not self-supporting. However these values may not be applicable for the Nicobar region where the level of organic production of the ambient waters as well as of the reef is considerably higher. But it lends support to the contention raised by Gordon and Kelly (*op. cit.*) that there is considerable variability between different coral reefs even at the level of total community metabolism.

It can also be seen that the rate of production and consumption are almost similar on the Manauli reef and Minicoy reef which is a typical oceanic island reef. Consumption is very low. The difference between the two stations decreases to a minimum of 0.14 ml O_2 /cm/sec at Manauli, 0.19 ml O_2/cm/sec at Minicoy and—1.35 ml O_2/cm/sec at Andamans. This may not be fully representing the total respiration of the entire reef community. Hence the values for true net production have to be taken only with caution. The minimum level is attained on both the oceanic island reefs during the pre-dawn period, while on the Manauli reef this level is attained after dusk.

While considering the reef productivity, certain ecological factors that have bearing on these values have also to be taken into account—viz., the productivity of the surrounding waters, and the seasonal variation in the light penetration brought about by the influence of the monsoons. At all the stations, the productivity of the ambient waters was also measured using ^{14}C technique, as indicated earlier. The waters around the Manauli reef have been found to possess a very high rate of organic production throughout the year without much seasonal variation (Prasad and Nair, 1963). By light and dark bottle oxygen technique it was found that the surface waters during March-April produce 144-475 mg C/m^3/day. The standing stock of phytoplankton and suspended matter, dead and dissolved organic matter etc., reduce the depth of the euphotic zone. The 1% light depth, as measured by a Tinsley irradiance meter was between 6 and 8 metres in the shallow regions of the Gulf of Mannar, whereas in Minicoy and Andaman region the standing stock of plankton and suspended matter is considerably less. Outside the lagoon the 1% light depth extends up to 90 metres while the entire lagoon comes within the euphotic zone during sunny days. The rate of organic production in both the oceanic regions are of the same order of magnitude—6.90 mg C/m^3/day in Andamans and 6.45 mg C/m^3/day in Minicoy (Prasad and Nair, 1958). If the variations noted in the magnitude of organic productivity of the ambient waters are also taken into account the actual net production by the reef organisms alone will be very much reduced on Manauli reef as compared to the other two reefs. However, as the incident radiation is uniformly high all through the year the same rate of production will be uniformly maintained for the whole year. Hence it can be concluded that an annual production of 2500 gC/m^2 can be expected over the Gulf of Mannar reefs. In Minicoy and Andamans, on heavily overcast days and rainy days during the monsoon period, the rate of production per unit area should be expected to fall by 50% (Steemann Nielsen and Jensen, 1957). Considering the seasonal variation brought about by the change in incident radiation together with the contribution by the standing stock of plankton in the lagoon, an annual production of 3000 gC/m^2 can be expected on Minicoy reefs. Incidentally it may be pointed out that earlier studies have shown that the Minicoy waters are the most productive in the Laccadive Sea. The organic productivity of these two reefs in thus comparable to that of the Pacific atolls which range from 1500 $gC/m^2/year$ to 3500 $gC/m^2/year$ (Kohn and Heifrich, 1957, Table 3).

Though the Andaman reef produces 1200 $gC/m^2/year$ the respiratory requirements of the organisms far exceed production and hence the reef in the North Bay at least seems to be non-autotrophic. The efficiency of gross productivity is also low here because of the comparative sparseness of phytoplankton and paucity of benthic algae. The utilization of energy is confined to the few hours of day when solar radiation is at its highest. However, other reefs in the Andaman Sea especially of the Nicobar group of islands may be having a different level of total community metabolism. Further work on the Nicobar reefs would reveal the contribution made by the coral reefs towards the economy of the Andaman Sea which is rich in living resources.

Summary

The paper deals with the results of primary productivity studies on three coral reefs: Manauli (Gulf of Mannar), Minicoy (Laccadive Sea) and Andamans (Bay of Bengal).

^{14}C technique was used to measure the productivity of the ambient waters and flow respirometry technique for reef productivity.

Manauli and Minicoy reefs were found to be autotrophic and Andaman reef non-autotrophic.

The ambient waters are very productive in the Gulf of Mannar, while in Minicoy and Andamans the values are of a typical oceanic station.

The Manauli reef with uniformly high incident radiation maintains a constant rate almost throughout the year, while in Minicoy and Andamans the influence of the weather brings in a certain amount of seasonal variation.

It has been calculated that Manauli reef produces 2500 gC/m^2 and Minicoy reef produces 3000 gC/m^2 annually (net). Though the Andaman reef produces 1200 $gC/m^2/year$ the respiratory requirement of the reef organisms is

far higher. Hence it is not self-supporting. But the level of community metabolism in the adjacent. Nicobar reefs would be more akin to that of the Minicoy reef and so these reefs would be contribution to the economy of the Andaman Sea.

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PRODUCTIVITY STUDIES ON SOME HERMATYPIC CORALS BY MEANS OF BOTH OXYGEN MEASUREMENTS AND ^{14}C METHOD

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ABSTRACT

The hermatypic corals harbour boring filamentous algae in their skeleton as well as symbiotic zooxanthellae in their soft tissue. These imprisoned algae produce much more quantity of oxygen by photosynthesis than the respiratory needs of the coral. Various attempts have been made in the past to estimate the oxygen production of corals and there was apparently disagreement among authors on the role of boring algae in the total production. In this work an attempt is made to evaluate the percentage of oxygen production contributed by the boring algae and the symbionts of a few species of reef building stony corals from Palk Bay and Gulf of Mannar around Mandapam (S. India). The gross production was estimated by dark and light bottles by Winkler technique, converting the oxygen values into carbon equivalents. The share of zooxanthellae was then determined by incubating the isolated symbionts with $NaH^{14}CO_3$. A marked difference was observed in the two sets of values thus obtained. In the light of the present results the role of the boring algae in the productivity of reef corals is discussed.

INTRODUCTION

Hermatypic scleractinian corals are known to produce more quantity of oxygen than is needed for their respiration during day time, by the photosynthetic activity of their imprisoned algae (Yonge, 1937, 1957; Yonge *et al.*, 1932; Odum and Odum, 1955; Kanwisher and Wainwright, 1967). The imprisoned algae in a coral colony comprise the symbiotic zooxanthellae and the boring filamentous algae found in the subsurface skeleton and between the polyps (Odum and Odum, 1955). Kawaguti (1944) has shown that in *Acropora corymbosa* the symbiont is *Gymnodinium symbiodinium*. A large number of organisms such as sponges, bryozoans, polychaetes and molluscs may be found as epizoites or as borers along with several microscopic acellular organisms, on a coral skeleton. Odum and Odum (op. cit) working on the trophic structure and productivity of a windward coral reef community on Eniwetok Atoll, have concluded that "the zooxanthellae (in the coelenterate polyps) comprised only about 6% of the total plant portion, filamentous algae embedded in the skeleton making up the bulk of the plant material". They thus attributed comparatively negligible role to the symbionts in the total plant matter in a coral colony. Recently Kanwisher and Wainwright (1967) have reported that "in the Florida reef corals, the boring green algae contribute very little indeed" to the productivity. According to these authors, the symbiotic zooxanthellae contribute about 90% of the total productivity of corals. The present study is an attempt to determine the primary production of a few species of reef corals of Palk Bay and Gulf of Mannar around Mandapam in South India, by both oxygen measurements by Winkler method and ^{14}C technique, and to compare the values.

MATERIAL

The following species of corals were selected for the present study.

Order Scleractinia
Suborder Astrocoeniina
Family Pocilloporidae
1) *Pocillopora damicornis* (Linnaeus)

Family Acroporidae
2) *Acropora corymbosa* (Lamarck)
3) *A. erythraea* (Klunzinger)
4) *Montipora divaricata* Brüggemann

Suborder Fungiina
Family Poritidae
5) *Goniopora stokesi* Milne Edwards and Haime
6) *Porites solida* (Forskål)

Suborder Faviina
Family Faviidae
7) *Favia pallida* (Dana)
8) *Favites abdita* (Ellis and Solander)
9) *Goniastrea pectinata* (Ehrenberg)
10) *Cyphastrea microphthalma* (Lamarck)

The corals were collected from the fringing reefs of Palk Bay and Gulf of Mannar during low tides and brought to the aquarium in large polythene buckets. The associated animals such as sponges, bryozoans, polychaetes and the larger attached algae as far as possible were carefully removed from the surface. Specimens whose skeletons were found to be attached by borers were discarded. The specimens were then cut into convenient size. In the case of large massive species the upper living zone with the band of filamentous algae was chipped out. Exposure to air was completely avoided except for a few minutes when they were taken out to chisel to pieces. The corals were then kept in an open aquarium tank for 2 to 4 days to get them acclimatised to the conditions and to let them recover from any injury to the tissues during transportation and subsequent handling. All the corals used in the present experiments were collected more or less at a depth of 50 cm at low tide.

METHODS

Each specimen was subjected to two sets of experiments, to determine 1) the gross production and 2) the production by the symbiotic zooxanthellae alone, both for a unit time. The gross production was estimated by the usual dark and light bottle method and the share of symbionts by ^{14}C method. For each species the experiments were repeated with two samples and the average value was taken for interpretation of the results.

Oxygen estimation

Air-tight dark and light atlas jars with a capacity of 1040 ml were used in oxygen estimations. To make them light-proof the outer side was coated with black paint and then covered with a black cloth. The weight of the corals used ranged from 64 to 125 grams (weight and volume were determined at the cessation of the experiments). The respirometers were set in large plastic buckets and were tightly closed under water. The bottles were then left in a large open tank 6x3½x1¼ metres at a depth of about 50 cm. The depth was adjusted to be almost the same at which the specimens were collected. Since corals show a higher rate of activity at about noon (Sargent and Austin, 1954; Goreau, 1961) our experiments were conducted mostly between 10.30 a.m. and 12.30 p.m. in the months of February, June, July and September, all under bright sunlight. On introduction into the respirometer it has been noted that the polyps of most of the species got fully expanded. The water temperature of the aquarium tank during the season of the experiments varied from 30 to 31.5°C but showed no marked change during the experimental period for a single species. The water in the experimental tank was emptied and refilled at intervals to prevent any marked rise of temperature. All the experiments were precisely adjusted for one hour. At the termination of the experiment the bottles were gently shaken and about 160 ml of water were siphoned out for oxygen estimation by the Winkler technique. Corrections for the volume of the coral were applied in calculating the total production or consumption by the coral. Controls were invariably run concurrently and necessary corrections to the values were made. The production and consumption for a specimen were estimated on adjacent days almost at the same time and same temperature and light intensities. Details of the species, weight and volume of the specimens used, the average of water temperature and the initial and final oxygen values are listed in Tables 1 and 2. Table 3 shows total production and the ratio of production by consumption for the various species.

Estimation of carbon fixed by zooxanthellae

The weight and volume of the corals that were used for the estimation of their oxygen production and consumption, were determined and the corals crushed in a porcelain mortar with filtered sea water generally within 24 to 48 hours after the oxygen estimation. The supernatant yellow solution containing the zooxanthellae was decanted. The decantation was repeated until the microscopic examination of the decant showed no more zooxanthellae. The whole solution was then centrifuged at high speed, the resulting pellet was repeatedly washed to remove the animal tissue and the attached mucus and made up to 100 ml in filtered sea water. In most of the species the decanted yellow solution was very thin but in some cases it was thick due to the presence of excessive quantity of mucus. The extraction of the zooxanthellae was completed within 1 to 1½ hours after crushing of the corals. The symbionts in the various species ranged from 8 to 12 μ in diameter. A few microscopic, actively moving organisms were seen in some species along with the zooxanthellae. The residue in the mortar (i.e. the skeleton) still retained the green colour indicating that most of the boring algae were left in the skeleton. Moreover microscopic examination of the extract did not reveal any broken pieces of filamentous algae. 5 ml of the aliquot was then added to the filtered sea water in a pyrex light bottle with a capacity of 265 ml. One ml of $NaH^{14}CO_3$ was added after covering the bottle with a black cloth. A control was set concurrently. The bottles were then incubated after removing the cover, under bright sunlight in the same tank almost at the depth where oxygen estimation was carried out. They were shaken at intervals to keep the algae in suspension and the incubation was stopped exactly after one hour, by covering the bottles again with a black cloth. The bottle was then well shaken and 20 ml of the water with the algae was filtered through a membrance filter in a filtering unit under a pressure of + 1.5 kg. The control was also suitably filtered. The filters were dried in a dessicator and the radioactivity was determined by a 2π Proportional Counter using Burshane gas. In calculating the total radioactivity of the zooxanthellae of any sample, necessary correction for both control and background was applied.

One ml of the filtrate was acidified with HCl in a tinfoil container and evaporated to dryness and then tested for radioactivity. But in most of the cases no appreciable count was detected indicating the loss through filtrate was comparatively negligible. Preliminary experiments showed a steady increase in the radioactivity of the filters in the first three hours. But after three hours the increase was not significant. This shows that the zooxanthellae were alive during our experimental period and were actively incorporating radioactive carbon by photosynthesis. As in the case of oxygen estimation the average values of two experiments were used for the interpretation of the results. All values were corrected to two decimal places. The whole experiment, i.e. from crushing to filtering, lasted about 2 to 2½ hours. The details of the results are presented in Table 4. The equivalent carbon of oxygen was calculated assuming a PQ of 1.25.

Discussion of the Results

The results of the present experiments presented in Tables 1, 2 and 3, also clearly indicate that, as already pointed out by Kanwisher and Wainright (1967), neither the weight nor the volume of a coral colony is in proportion to its productivity. The surface area may be a more reliable parameter but its estimation in several cases especially in slender ramose forms is likely to go wrong to a marked degree. The production and consumption, needless to say, are factors regulated by the quantity of the imprisoned plankton and the animal tissue present and the physiological state of them. This is also influenced by several other external factors (vide infra). In the ten species of corals which we used in the experiments of short duration the ratio of production to consumption varied from 1.97 to 3.58. The lowest ratio of 1.97 was shown by *Goniastrea pectinata* and the highest of 3.58 by *Porites solida.* In most of the other species the values ranged from 2.3 to 3.58. *Acropora, Pocillopora* and *Goniopora* showed a very high rate of production as well as consumption indicating a high metabolic rate. The ratio of production by consumption is more fluctuating, if the results of the twenty experiments are considered separately, where they are from 0.58 to 4.27.

Goreau and Goreau (1959) have shown that the rate of calcification in corals is in part dependent on the presence of zooxanthellae, though several other factors such as light and 'inherent species specific factors' may influence (Goreau, 1961). The present results also indicate that the zooxanthellae of the faster growing genera like *Acropora* and *Pocillopora* have a comparatively higher rate of photosynthetic activity when compared to the slower growing genera such as *Favia, Favites, Goniastrea* and *Porites.*

The carbon fixed by the different corals per hour, measured by both the Winkler technique and ^{14}C methods, are presented in Table 5. The carbon values obtained by the latter method are adjusted to net by multiplying the experimental values by 0.96 (Steemann Nielsen, 1964). Except in the case of *Goniastrea pectinata* and *Goniopora stokesi* the net values of carbon fixed by the zooxanthellae is always less than the net production measured by light bottle. In *Goniopora stokesi* the two values are almost similar, allowing for a small percentage of experimental error. In the case of *Goniastrea pectinata* it is possible that the potential production of the specimens used might not have been realised in the light bottle, or the zooxanthellae might have multiplied during the intervals (Kanwisher, 1966). But the latter possibility is found in all species used. *Montipora divaricata* shows a very low value with ^{14}C incubation in spite of the higher values obtained by light and dark bottles. We are unable to explain this wide discrepancy, though the experiments were repeated, but always showed a very low radioactivity. The wide range of ratio of the net productions measured by the two methods in the different genera and species is also noteworthy. While the net production of carbon obtained by the light bottle is by both the zooxanthellae and the boring filamentous algae (whatever may be the share of the latter) the ^{14}C values account only for the zooxanthellae. While Odum and Odum (1955) attributed 94% of the total plant matter of a coral head to the boring algae in the Eniwetok Atoll, Kanwisher and Wainwright (1967) attributed only less than 10% of the total productivity of a coral to the boring algae in the Florida reefs. We could not attempt to estimate separately the production of boring algae but our preliminary experiments clearly indicate that the filamentous algae are a major constituent of the total plant matter of the reef corals and are capable of photosynthesising. However, it is apparent that the difference in the net productions obtained by the light bottle and the ^{14}C method is not attributable to the boring algae, as may be clear from the following general discussion.

General Discussion

There has been much variability in the carbon production values of the tropical oceanic waters, estimated by ^{14}C and light and dark bottles using Winkler reagents. The former technique though regarded as more sensitive, the values obtained thus were lower by a factor of 10-100 (Ryther, 1954). This discrepancy in the values had been mainly because of use of inappropriate value for PQ (McAllister *et al,* 1961) and also because of undue prolongation of the experimental time (Steemann Nielsen and Kholy, 1955), and the physiological state of the phytoplankon. Recent investigations have also pointed out the importance of proper standardisation of the ^{14}C stock solutions which is an essential pre-requisite for the proper assessment of the values (Steemann Nielsen, 1965; Nair, 1966). Even though, there is controversy as to what exactly is being measured by ^{14}C technique (cf. Strickland, 1960) it has now been agreed that in short term experiments the value obtained is something between gross and net production for phytoplankton, but probably near to the net. The above investigations, however, are on the marine phytoplankton or cultures of phytoplankton in the laboratory conditions. With regard to the symbiotic zooxanthellae no previous similar work is known to the present authors and very little is actually known on the physiological changes that may take place on the algae on their separation from the host tissue. Even if the values of respiration is added to the net values of carbon fixed by the zooxanthellae and adjusted to gross in the values given in Table 5, excepting in *Goniastrea pectinata* and *Goniopora stokesi* such an adjusted gross value is less than the gross production obtained by light and dark bottle technique. In other words the oxygen consumption values being constant in both cases, the net production measured by light bottle, as already indicated, is of a higher order. The higher values obtained for the two species are, however, not in agreement with the result with the other species. This disparity in the two sets of values obtained for net productions in corals can be due to the effect of several factors either acting independently or collectively.

TABLE 1. *Oxygen production by reef corals—light bottle experiments. Genera and species are listed in alphabetical order*

No.	Name of species	Wt. in grams	Vol. in ml	Vol. of respirometer in cc	Date	Time	Average water temp.	Control		Coral		Difference from control	Net production of oxygen mg/hr.
								Initial oxygen mg/l	Final oxygen mg/l	Initial oxygen mg/l	Final oxygen mg/l		
1a.	*Acropora corymbosa*	90	40	1045	1-7-'68	10.35-11.35	29.5	5.33	5.33	5.33	8.03	2.70	2.71
1b.	" "	72	33	-do-	2-7-'68	10.35-11.35	29.5	5.22	5.22	5.22	8.14	2.92	2.96
2a.	*Acropora erythraea*	72	36	-do-	16-2-'68	11.40-12.40	30	6.70	6.70	6.70	9.96	3.26	3.29
2b.	" "	70	35	-do-	19-2-'68	11.40-12.40	30	7.01	7.05	7.01	9.39	2.34	2.36
3a.	*Cyphastrea microphthalma*	110	56	-do-	5-9-'68	10.20-11.20	30.5	5.43	5.52	5.43	6.86	1.34	1.33
3b.	" "	102	52	-do-	5-9-'68	11.30-12.30	30.5	5.43	5.43	5.43	6.31	0.88	0.87
4a.	*Favia pallida*	142	84	-do-	17-7-'68	10.30-11.30	29.5	5.59	5.59	5.59	7.38	1.79	1.72
4b.	"	115	68	-do-	18-7-'68	10.30-11.30	29.5	5.70	5.70	5.70	7.20	1.50	1.46
5a.	*Favites abdita*	88	48	-do-	23-2-'68	11.20-12.20	30	5.49	5.49	5.49	5.79	0.30	0.30
5b.	"	84	45	-do-	24-2-'68	11-30-12.30	30	5.57	5.57	5.57	6.68	1.11	1.11
6a.	*Goniastrea pectinata*	98	49	-do-	21-2-'68	11.40-12.40	30	4.82	6.12	4.82	6.46	0.34	0.34
6b.	" "	102	51	-do-	22-2-'68	11.30-12.30	30	5.49	5.49	5.49	6.05	0.56	0.56
7a.	*Goniopora stokesi*	125	82	-do-	22-7-'68	10.40-11.40	30	5.62	5.73	5.62	10.66	4.93	4.74
7b.	"	90	50	-do-	23-7-'68	10.25-11.25	29.5	5.51	5.51	5.51	7.95	2.44	2.43
8a.	*Montipora divaricata*	107	60	-do-	28-8-'68	9.45-10.45	30.0	5.36	5.36	5.36	8.81	3.45	3.43
8b.	" "	70	35	-do-	28-8-'68	11.00-12.00	30.0	5.39	5.39	5.39	8.92	3.53	3.56
9a.	*Pocillopora damicornis*	64	31	-do-	31-8-'68	10.25-11.25	30.5	5.36	5.36	5.36	9.32	3.96	4.02
9b.	" "	90	40	-do-	31-8-'68	11.35-12.35	30.5.	5.35	5.35	5.35	10.09	4.74	4.76
10a.	*Porites solida*	100	56	-do-	21-6-'68	10.45-11.45	30	4.99	4.99	4.99	6.07	0.08	1.07
10b.	"	107	60	-do-	22-6-'68	11.00-12.00	30	4.99	4.99	4.99	6.47	1.48	1.46

TABLE 2. *dark bottle experiments with corals. The weight and volume of corals and the volume of the respirometer are same as indicated against the respective numbers in Table 1.*

No.	Name of species	Date	Time	Average temperature	Control: Initial oxygen mg/1	Control: Final oxygen mg/1	Coral: Initial oxygen mg/1	Coral: Final oxygen mg/1	Difference	Oxygen in mgs. used by corals	Gross production in mg. (i.e. net productiod plus consumption)
1a.	*Acropora corymbosa*	2-7-'68	10.35-11.35	29.5	5.22	5.22	5.22	2.92	2.30	2.31	5.02
1b.	" "	1-7-'68	10.35-11.35	29.5	5.33	5.33	5.33	3.37	1.96	1.98	4.94
2a.	*Acropora erythraea*	19-2-'68	11.40-12.40	30	7.01	5.86	7.01	5.19	1.67	1.68	4.97
2b.	" "	16-2-'68	11.40-12.40	30	6.7	6.44	6.7	4.90	1.54	1.55	3.91
3a.	*Cyphastrea microphthalma*	5-9-'68	11-30-12.30	30.5	5.43	5.39	5.43	4.48	0.91	0.90	2.24
3b.	" "	5-9-'68	10.20-11.20	30.5	5.43	5.43	5.43	4.75	0.68	0.67	1.57
4a.	*Favia pallida*	18-7-'68	10.30-11.30	29.5	5.69	5.69	5.69	4.55	1.14	1.10	2.82
4b.	"	17-7-'68	10.30-11.30	29.5	5.59	5.55	5.59	4.77	0.78	0.76	2.22
5a.	*Favites abdita*	24-2-'68	11.30-12.30	30	5.31	4.90	5.31	4.38	0.52	0.52	0.82
5b.	"	23-2-'68	11.20-12.20	30	5.49	5.08	5.49	4.82	0.26	0.26	1.37
6a.	*Goniastrea pectinata*	22-2-'68	11.20-12.20	30.0	5.49	5.30	5.49	5.04	0.26	0.26	0.60
6b.	" "	21-2-'68	11.40-12.40	30.0	6.12	6.05	6.12	5.38	0.67	0.67	1.23
7a.	*Goniopora stokesi*	23-7-'68	10.25-11.25	29.5	5.51	5.51	5.51	3.51	2.00	1.93	6.67
7b.	" "	22-7-'68	10.30-11.30	29.5	5.70	5.70	5.70	4.22	1.48	1.42	3.85
8a.	*Montipora divaricata*	28-8-'68	11.00-12.00	30	5.39	5.39	5.39	3.56	1.83	1.82	5.25
8b.	" "	28-8-'68	9.45-10.45	30	5.36	5.36	5.36	4.07	1.29	1.30	4.86
9a.	*Pocillopora damicornis*	31-8-'68	11.25-12.25	30.5	5.28	5.28	5.28	3.30	1.98	2.01	6.03
9b.	" "	31-8-'68	10.25-11.25	30.5	5.28	5.28	5.28	2.94	2.34	2.35	7.11
10a.	*Porites solida*	22-6-'68	11.00-12.00	30	4.99	4.99	4.99	4.40	0.59	0.58	1.65
10b.	"	21-6-'68	10.45-11.45	30	4.99	4.92	4.99	4.51	0.41	0.40	1.86

TABLE 3. *Oxygen production by reef corals, calculated from two experiments each. Details of separate experiments are as in Table* 1 *and* 2.

No.	Name of species	Total weight in gms.	Total vol. in ml.	Average water temp °C	Net production of oxygen in mg/hr	Oxygen consumed in mg/hr	Grass production in mg/hr	Production / Consumption
*1a+1b.	*Acropora corymbosa*	162	73	29.5	5.67	4.29	9.96	2.32
2a+2b.	*Acropora erythraea*	142	71	30	5.65	3.23	8.88	2.75
3a+3b.	*Cyphastrea microphthalma*	212	118	30.5	2.20	1.57	3.77	2.40
4a+4b.	*Favia pallida*	257	152	29.5	3.18	1.86	5.04	2.71
5a+5b.	*Favites abdita*	172	93	30	1.41	0.78	2.19	2.81
6a+6b.	*Goniastrea pectinata*	200	100	30	0.90	0.93	1.83	1.97
7a+7b.	*Ganiopora stokesi*	215	152	29.5	7.17	3.35	10.52	3.14
8a+8b.	*Montipora divaricata*	154	71	30	6.99	3.12	10.11	3.24
9a+9b.	*Pocillopora damicornis*	154	71	30.5	8.78	4.36	13.14	3.01
10a+10b.	*Porites solida*	207	116	30	2.53	0.98	3.51	3.58

* Numbers refer to Tables 1 & 2.

TABLE 4. *Details of incubation of zooxanthellae with $NaH^{14}CO_3$. Genera and species are listed alphabetically*

No-	Name of species	Weight gms.	Vol. ml	Date	Duration	Average water temp. °C	Counts* p/m	Carbon fixed by zooxanthellae mg/hr. Adjusted to net
1a.	*Acropora corymbosa*	90	40	3-7-'68	10.45-11.45	30	184250	0.64
1b.	" "	72	33	4-7-'68	10.45-11.45	30	188375	0.65
2a.	*Acropora erythraea*	72	36	19-2-'68	11.40-12.40	30	132000	0.46
2b.	" "	70	35	20-2-'68	11.40-12.40	30	150700	0.52
3a.	*Cyphastrea microphthalma*	110	56	7-9-'68	11.00-12.00	30.5	67100	0.24
3b.	" "	102	52	6-9-'68	11.00-12.00	30.5	95150	0.33
4a.	*Favia pallida*	142	84	19-7-'68	11.15-12.15	30	67650	0.24
4b.	"	115	68	20-7-'68	11.15-12.15	30	45375	0.15
5a.	*Favites abdita*	80	48	28-2-'68	11.30-12.30	30	20900	0.07
5b.	"	84	45	27-2-'68	11.30-12.30	30	60775	0.21
6a.	*Goniastrea pectinata*	98	49	24-2-'68	11.35-12.35	30	46750	0.17
6b.	" "	102	51	23-2-'68	11.35-12.35	30	52250	0.18
7a.	*Goniopora stokesi*	125	82	25-7-'68	10.40-11.40	30	422125	1.46
7b.	" "	90	60	24-7-'68	10.40-11.40	30	22000	0.77
8a.	*Montipora divaricata*	100	50	28-8-'68	10.40-11.40	30	4675	0.02
8b.	" "	70	35	29-8-'68	10.40-11.40	30	2200	0.01
9a.	*Pocillopora damicornis*	64	31	2-9-'68	10.30-11.30	30.5	308550	1.07
9b.	" "	90	40	3-9-'68	10.30-11.30	30.5	291775	1.01
10a.	*Porites solida*	100	56	24-6-'68	11.00-12.00	30	27500	0.09
10b.	"	107	60	25-6-'68	11.00-12.00	30	31350	0.11

* Counts are given after making the necessary correction for the control and the back ground.

TABLE 5. *Comparison of values of primary production of reef corals estimated by oxygen method and ¹⁴C technique*

No.	Name of species	Weight in gms.	Carbon equivalent to net O_2 (PQ=1·25) mg.	Carbon equivalent to respiration mg.	Gross Carbon mg.	^{14}C values of carbon adjusted to net, mg.	Percentage realised by ^{14}C against the net production measured by l. bottle
1.	*Acropora corymbosa*	162	1.70	1.29	2.99	1.29	75.88
2.	*Acropora erytharea*	142	1.69	0.97	2.66	0.98	57.99
3.	*Cyphastrea microphthalma*	212	0.66	0.47	1.13	0.57	86.36
4.	*Favia pallida*	257	0.95	0.56	1.51	0.39	41.10
5.	*Favites abdita*	172	0.43	0.23	0.66	0.28	65.10
6.	*Goniastrea pectinata*	200	0.27	0.28	0.55	0.35	129.60
7.	*Goniopora stokesi*	215	2.16	1.00	3.16	2.23	103.20
8.	*Montipora divaricata*	170	2.09	0.94	3.03	0.03	1.44
9.	*Pocillopora damicornis*	154	2.63	1.31	3.94	2.08	79.10
10.	*Porites solida*	207	0.76	0.29	1.05	0.20	26.31

A proper assessment of PQ value is essential in converting the oxygen values into equivalent carbon. Ryther (1956) has pointed out that a PQ of 1 is largely an experimental artifact and suggested a value of 1.25 for phytoplankton of natural waters. Based on the results of ^{14}C and oxygen measurments of the coastal waters, Prasad and Nair (1962) suggested a PQ of 1.3. It appears from our results that a PQ of 1 is too low for the symbiotic zooxanthellae and a value of 1.25 is more reasonable and is adopted in this work.

Interference of chemical agents in the Winkler technique is a factor that might influence the results obtained (Kanwisher and Wainwright, 1967). The role of micro-organisms in the respiration of corals is a factor that needs consideration. There are a large number of them present in a coral head and they are observed along with the isolated zooxanthellae. If they respire both in the dark and light bottles this should introduce no systematic errors (Strickland, 1960) in the oxygen values. Yonge (1937) has noted that about 34.3% of the apparent respiration of the *Acropora* is due to the rapid consumption of mucus by bacteria during the experimental period. But as pointed out by Sargent and Austin (1954), for short term experiments where the corals are subjected to minimum disturbance, correction for mucus oxidation is of only secondary importance.

The algae are known to excrete a part of their photosynthetic product in the form of soluble products like glycerol aminoacids and peptides (Hellebust, 1965; Muscatine, 1965, 1967) when incubated with radioactive carbon. According to Hellebust (1965) the different algae on incubation, under full sunlight with radioactive carbon at a temperature of 18 °C for five hours, excreted as much as 9 to 52% of their photosynthate as soluble by-products. Muscatine (1967) working with the symbionts of *Pocillopora* has stated that, on incubation at a temperature of 25° C they lost as much as 12% of their photosynthetic product into the medium in the absence of any tissue homogenate, in the first hour of incubation at a light intensity of 4400 to 6600lu/m^2. The rate of excretion was shown to be of the magnitude of 36.8% in the presence of the host tissue homogenate. Separation of the zooxanthellae from the host tissue might have marked effect on their physiological activities that might result in a retardation of their photosynthetic activity in the free medium.

The host tissue is believed to accelerate the photosynthetic activity of the symbionts either by shading and providing optimum conditions of light or directly by chemical catalysis (Muscatine, 1967). Goreau and Goreau (1960) have suggested that *in vivo* these soluble by-products will be transferred to the host tissue and will be utilised. As we could not detect any marked loss as soluble products of photosynthesis in our experiments, our results can be modified only in the light of earlier findings. It appears to be only reasonable to allow a loss of 5% of the total photosynthetic product of the zooxanthellae as soluble by-products in the present series of experiments (Muscatine, personal communication).

When zooxanthellae are isolated and left in a free medium for incubation, they are suddenly subjected to a much greater intensity of light than in their natural habitat. It is quite likely that the optimum conditions are not met with in the free medium. Further, the present experiments were carried out under full sunlight at a depth of about 50 cm of water. It has already been pointed out by Hellebust (1965) that intense light may do damage to the cells during incubation with ^{14}C. But cell lysis may be regarded negligible during short periods of incubation (Muscatine, 1965). But as already been mentioned, a steady increase in carbon uptake in comparison with the controls for the first three hours of our incubation of zooxanthellae is suggestive that the cell lysis is negligible in the present cases. Yet another possibility is the loss of a few zooxanthellae during isolation and subsequent manipulation. This, however, will not be of any considerable measure since extreme care has been taken to avoid, as far as possible, such waste in the present set of experiments.

In spite of giving allowances for all these it is evident from the present results that the production measured by ^{14}C is generally less than what is obtained by oxygen measurements, though in two cases, viz., *Goniastrea pectinata* and *Goniopora stokesi*, the values by the former method were higher. If such difference could be an indirect evidence to the share of the boring algae in the overall productivity of the coral head, it would appear that this share would be rather high in certain cases (see Table 5).

We are at present unable to suggest the exact share of the filamentous algae in the gross production of corals of this area. Kanwisher and Wainwright (*op. cit*) attribute only 10% of the total production in Florida reef corals but it may be pointed out that there is always danger in extrapolating results from one place to another, for the content of symbiotic algae and the boring algae in corals may vary from region to region and even in different species.

Summary and Conclusions

The primary production of a few species of hermatypic scleractinian corals are estimated by both Winkler method and ^{14}C technique. The results emphasise that neither the weight nor the volume of corals can be taken as a unit for comparison of the production values of various species or even within the different specimens of a single species or part of the same specimen. The faster-growing genera like *Acropora* and *Pocillopora* have a higher metabolic rate than the slower-growing genera like *Favia, Favites, Goniastrea* and *Porites*.

In the ten species of corals used, the ratio of gross production by consumption varied from 1.97 to 3.58. The symbiotic zooxanthellae when isolated and incubated with radioactive carbon in filtered sea water under bright sunlight at a temperature of about 30° C, actively incorporated carbon by photosynthesis in the first two to three hours during which cell lysis is comparatively negligible.

The net values of incorporated carbon obtained by ^{14}C method are mostly less than the values obtained by the oxygen technique. It is probable that in the case of symbionts the ^{14}C values are nearer to the net production than to the gross.

The various external and internal factors that might have influenced the present results either directly or indirectly are briefly reviewed.

The boring filamentous and attached algae on a coral colony are decisively contributing towards the total production, but their share may vary in different species.

Acknowledgements

The authors are grateful to Dr. S. Jones, Director of this Institute, for his great interest throughout the course of this work. Our thanks are due to Mr. C. Mukundan of this Institute for critically reading through the manuscript and offering helpful suggestions. We sincerely thank Dr. Leonard Muscatine of the University of California and Dr. G. E. Fogg, University College, London, for a critical discussion of the results presented here. We wish to thank Mr. P. Etty, our colleague, for his willing help during the experiments.

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Discussion

MUSCATINE: I wonder if you have considered the possibility that zooxanthellae after removal from the corals may show retardation in activity. I mean, you cannot expect it to act as under natural conditions.

PILLAI: This is a factor that needs experimental confirmation for which we made no attempt. But it may be borne in mind that our incubation of zooxanthellae with ^{14}C was done for only one hour and invariably the experiments were terminated within 2 to 2½ hours from crushing of the coral to the final filtering. Separation of zooxanthellae from the host tissue might be influencing their photosynthetic activities. Moreover the illumination is not the same in natural and experimental conditions. These problems need further investigations.

AN ECOLOGICAL STUDY OF SOME POOLS NEAR MANDAPAM (SOUTH INDIA) FORMED AS A RESULT OF THE CYCLONE AND TIDAL WAVE OF 1964

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AN ECOLOGICAL STUDY OF SOME POOLS NEAR MANDAPAM (SOUTH INDIA) FORMED AS A RESULT OF THE CYCLONE AND TIDAL WAVE OF 1964*

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INTRODUCTION

A SEVERE cyclone and tidal wave[1] hit the south-eastern part of India on December 23, 1964 causing unprecedented devastation. Weather forecast for December 21 had indicated that a severe cyclonic storm had formed in the Bay of Bengal and was centred about 1,200 km. south-east of Madras and was expected to move in a westerly or west-north-westerly direction. By the morning of December 23 the cyclonic storm had crossed northeast coast of Ceylon and was lying over the Gulf of Mannar centred about 50 km. east of Tondi when north-westerly gales exceeding 75 km. per hour began lashing the coastal areas of Ramanathapuram district. The storm raced from the small hours of the morning and continued unabated till about 8 a.m. After a brief lull the direction of the gale abruptly changed to a south-westerly one bringing in further havoc. The cyclonic storm coupled with the high tide brought forth a huge tidal wave of about 25 feet height engulfing Dhanushkodi—a good part of Rameswaram Island, and the low-lying areas of the mainland (see Fig. 1, inset). With the reversal of the direction of wind during the cyclonic storm the flood waters receded leaving behind several pools teaming with living organisms. The ecological study of these pools was taken up about a month later when bioluminescence was noticed in some of the pools. The normal stimulus for the emission of living light being mechanical, the agitation of water by throwing a stone and by the swimming movements of fishes and prawns produced intense luminescence. A cursory examination of the water sample taken from one of the pools revealed an abundance of littoral diatoms and many Dinophyceae especially *Pyrocystis* which is normally found in the high seas in the tropics and also cause of bioluminescence (*cf.* Fritsch, 1948). Therefore a detailed investigation of the populations in these sheltered pools was taken up at the suggestion of Dr. S. Jones, Director, Central Marine Fisheries Research Institute, Mandapam Camp. The authors wish to express their sincere thanks for the profound interest he took in this work and also for giving valuable help and guidance. The authors are indebted to Dr. R. Raghu Prasad, Deputy Director and Dr. R. Subrahmanyan, Senior Research Officer for critically going through the manuscript and offering valuable suggestions. The authors thank Mr. K. J. Joseph, for assistance in the analysis of water samples and Mr. K. L. Kesavan for drawing the text figures.

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[1] It has been suggested by some meteorologists that it was not a tidal wave in the strict sense but the normal high tide water whipped up by a high-velocity wind.

After a preliminary survey of the area around Mandapam where several pools had formed, five of them spread over a distance of 2 km. were selected (Fig. 1). Though these pools were selected at random further analysis indicated that there is some divergence in the nature of the pools in their hydrological, planktological and faunistic characters. Pools 1, 2 and 4 were more saline and were akin to the adjoining lagoon, whereas 3 and 5 were of brackish nature. As the whole low-lying area was flooded by the tidal water it is not known how pools 3 and 5 maintained a lower salinity than the other three pools. It is possible that slow percolation from the lagoon and sea might have influenced the salinity in pools 1, 2 and 4 while in 3 and 5 there would have been greater dilution due to run off which is evidenced by the higher silicate content also. Pool 5 showed no trace of bioluminescence initially but with the blooming of *Pyrocystis* by the third week of March it became highly luminescent.

Weekly collections were made from all the pools, lagoon and the sea (Palk Bay). Water samples were analysed for salinity, phosphate and silicate using standard analytical techniques (Table I). Colour comparisons were made visually. 500 ml. of the water samples were sedimented and centrifuged and were made up 10 ml. and 1 ml. aliquots were counted on Sedgewick-Rafter type counting chamber. For the smaller and abundant organisms haemocytometer counts were taken. Continuous observations of a few factors were also made at regular intervals from the lagoon and pool 2 for a whole day so as to cover both the high and low tides (Fig. 2).

Prawns and fish were collected from all the pools on the same days using a drag-net (*kondodi-valai*) making a single haul from each pool. Regular observations were carried out for over two months from the beginning of February 1965 to the first week of April 1965. Thereafter, although the weekly collections were continued till all the pools dried up by about 19-5-1965 the water samples were analysed for salinity only.

Discussion of Results

Hydrology : The salinity varied widely from the initial to the final stage with the progress of summer and consequent evaporation. The slight fall on 16-2-1965 and 20-4-1965 was due to the rainfall on the previous days. Pools 1, 2 and 4 initially were of sea water-type (30-40‰) reaching hypersalinity (40-80‰) after about a month and ended up as brine water (>80‰). Pools 3 and 5 were brackish initially (<30‰). But in the final stage, pool 3 was hypersaline and pool 5 of brine water. The silicate concentration also was distinctly higher in the latter two pools. The high increase of silicate at the end of March might be due to the continuous churning of the bottom while fishing. The silicate values obtained here for the sea water were also higher than in the previous observations (Jayaraman, 1954), presumably because these samples were taken from very near the shore. The concentration of silicates together with salinity seemed to have influenced the composition of the dinophycean population.

Phosphate values were not found to vary significantly between the pools. Within the limits of experimental errors the depletion by the developing population was evident in all the pools. However, the values are by no means absolute and need be considered only as arbitrary, as the colour comparisons were very difficult due to the influence of detritus.

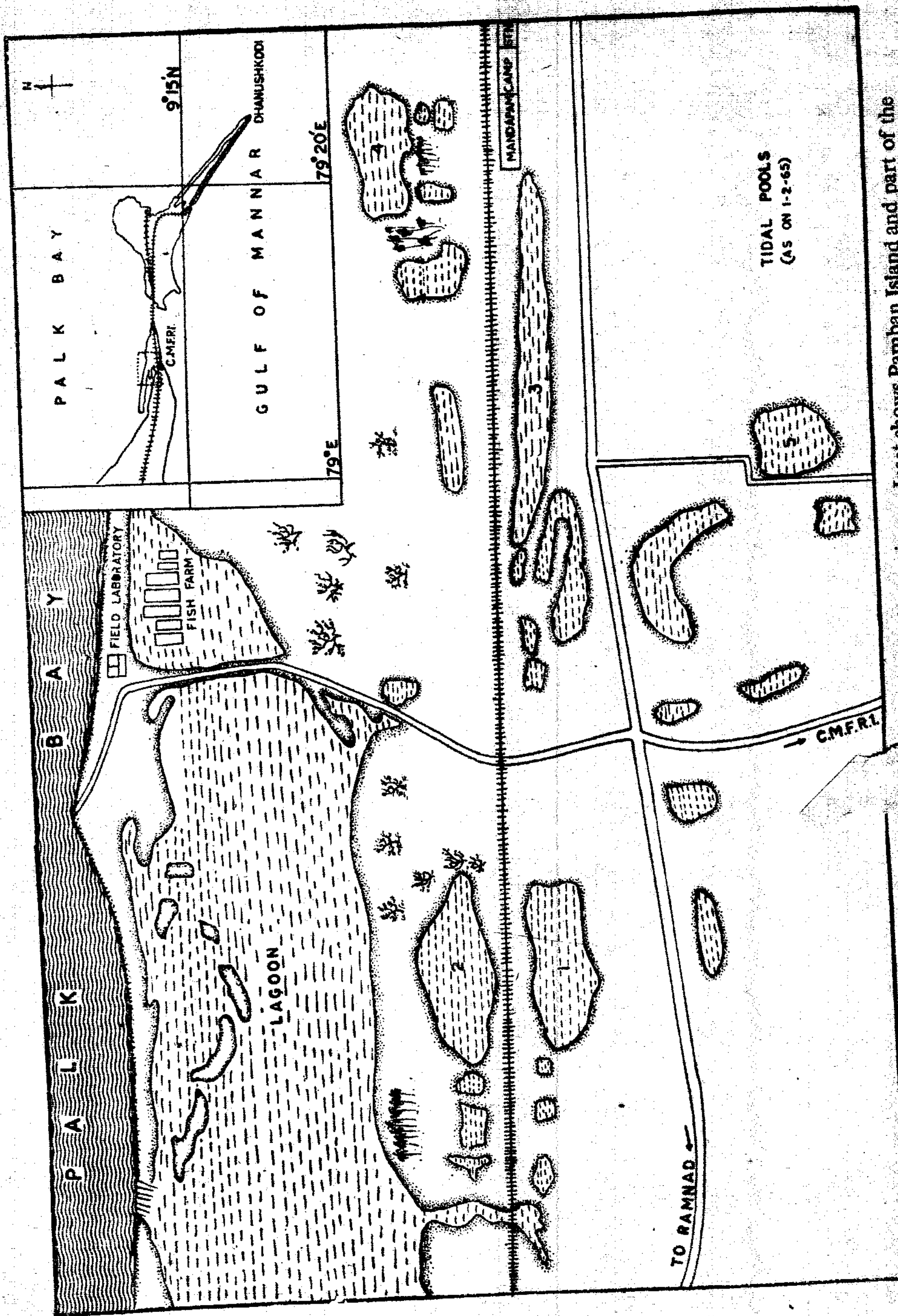

FIG. 1. Location of the tidal pools as at the beginning of the observations. Inset shows Pamban Island and part of the mainland which was worst hit by the cyclone. The dotted area has been enlarged.

There was a definite diurnal rhythm in the concentration of the oxygen following more or less the temperature pattern—with an afternoon maximum and a predawn minimum. The oxygen concentration in the pools was significantly lower

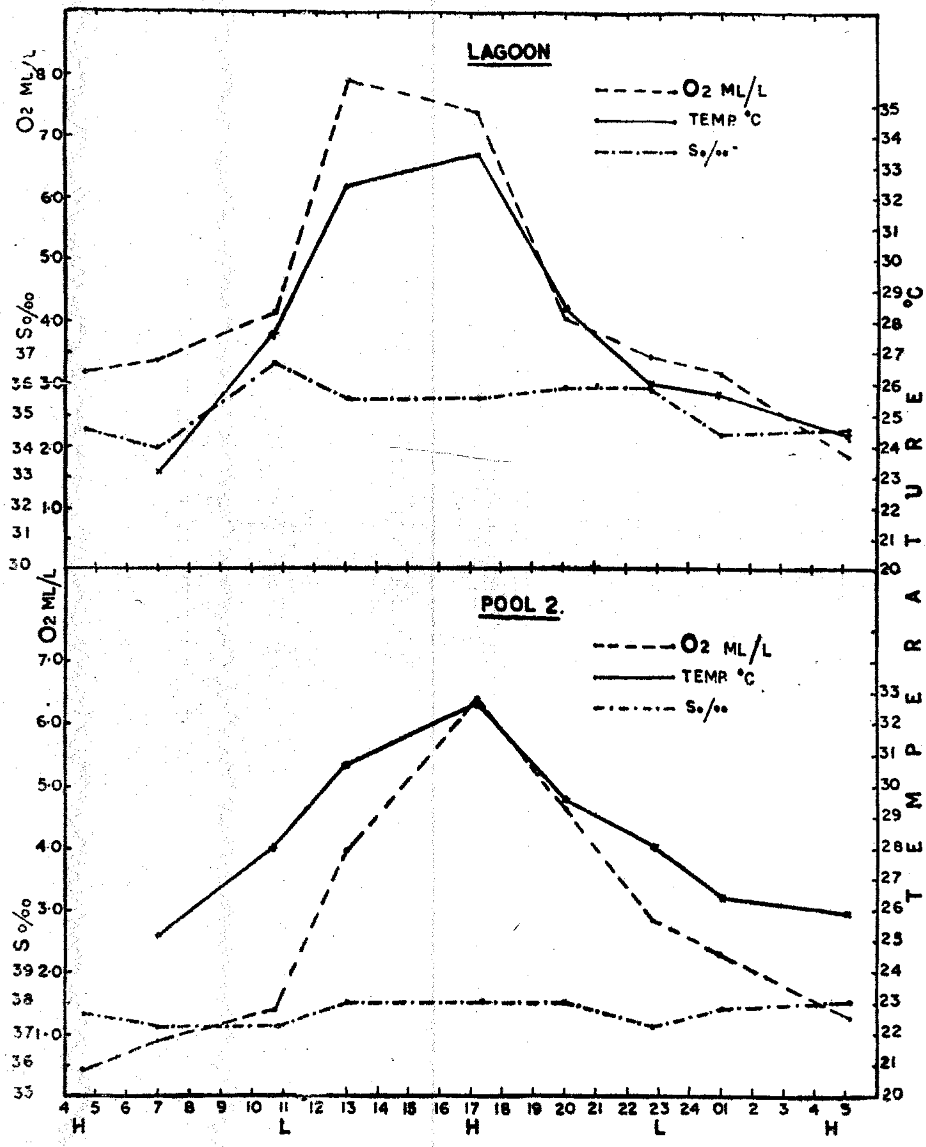

FIG. 2. Diurnal variation of oxygen, temperature and salinity in the lagoon and pool 2 from 0400 hours on 20-2-1965 to 0500 hours on 21-2-1965. L-Low Tide. H-High Tide.

than that of the sea which is an indication of the difference in the concentration of organisms between a natural environment and a special environment.

There was a definite diurnal rhythm in the concentration of the oxygen following more or less the temperature pattern—with an afternoon maximum and a pre-dawn minimum. The oxygen concentration in the pools was significantly lower

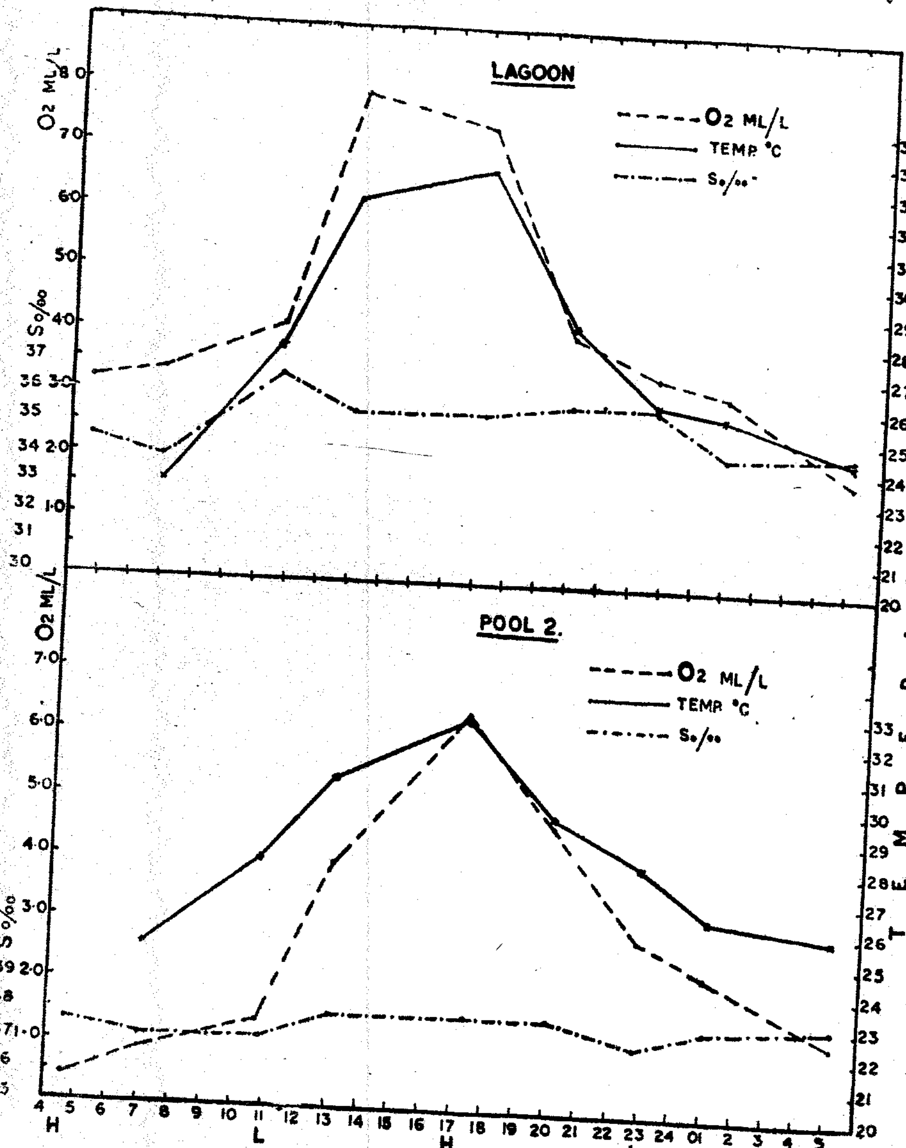

FIG. 2. Diurnal variation of oxygen, temperature and salinity in the lagoon and pool 2 from 0400 hours on 20-2-1965 to 0500 hours on 21-2-1965. L-Low Tide. H-High Tide.

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The temperature and oxygen values recorded here for the lagoon are lower and those of salinity and phosphate higher than those recorded by Tampi (1959). The differences observed may be due to the difference in the time of observations, the shallower nature of the lagoon and the influx of soil from surrounding areas after flooding of the lagoon during cyclone.

Phytoplankton : The phytoplankters were mostly composed of two members of Dinophyceae (*Pyrocystis* and *Peridinium*) and littoral diatoms belonging to the genera *Pleurosigma* and *Navicula* (Table II). Apart from these *Nitzschia*, *Cymbella* and also the blue green alga *Oscillatoria* were noticed occasionally. Since the commencement of the investigations, it was noticed that there was a distinct succession of the organisms with the progressive onset of summer and increase in salinity. The dominance of diatoms noticed in the first week of February was followed by members of Dinophyceae. In pool 3, *Pyrocystis* was noticed in abundance even at the start of the investigations but in pool 5, the appearance of this species took place only later. *Pyrocystis pseudonoctiluca* is a member of the Dinophyceae and is an abundant planktonic form occurring in most tropical and subtropical seas and is one of the diverse organisms responsible for bioluminescence. The individual cell is large and spherical with a pale yellow colour due to the presence of numerous small yellow-brown chromatophores. The organism responsible for bioluminescence in pools 1, 2 and 4 was *Peridinium*, whereas in 3 and 5 it was *Pyrocystis* though some others like *Ceratium*, *Gymnodinium* etc. also were noticed in very small numbers in all. In this connection it may be mentioned that several Dinophyceae are known to be luminescent viz. *Noctiluca*, *Pyrodinium*, *Ceratium*, *Peridinium*, *Prorocentrum*, *Gonyaulax*, *Blepharocysta* and *Gymnodinium* (Harvey 1952).

Pool 4 can be taken as a typical example where succession of organisms was found to have a definite pattern of sequence. From a preponderance of diatoms especially *Pleurosigma* of about 235,000 cells/1, *Peridinium* sp. gained dominance and attained an intensity of 246,000 cells/1 by the third week of February when the diatom intensity dwindled to a mere 6,000 cells. This was followed by the appearance of a flagellate *Carteria* (Chlamydomonadineae) in large numbers when the pool was drying up and the water reached hypersalinity. This flagellate developed almost to the exclusion of all other forms of phytoplankton and flourished even when the salinity was over 100‰. This, however, is not surprising since some flagellates, Cyanophyceae and shrimps are known to exist in brine water with salinities exceeding even 200‰ (*cf.* Kinne, 1964). The climax of the sequence of succession of organisms in pool 1 was also formed by the same flagellate, whereas in pool 2 it was by *Chilomonas* (Cryptomonadaceae), a colourless, saprophytic flagellate lacking in chromatophores.

It may be mentioned here that the conditions in these pools were of a special nature and were subject to the extremes from the initial to the final drying up stage. Hence it is possible that salinity and perhaps the silicate content too would have influenced to a large extent the succession and dominance of the various organisms.

Prawns : Penaeid prawns formed a good portion of the catches. They were identified and measured. Most of them were young ones which could hardly be differentiated as males and females. The total number, size range, dominant size groups and total weight were recorded for each sample. These are given in Table III.

A sizeable portion of the weekly catches was composed of prawns, the species represented being *Penaeus indicus* Milne Edwards, *P. merguiensis* de Man, *P. semisulcatus* de Haan, *P. monodon* Fabricius, *Metapenaeus affinis* (Milne Edwards) and *M. dobsoni* (Miers). In addition to them a few specimens of *Metapenaeus burkenroadi* (Kubo)[1], 2 specimens of *M. lysianassa* de Man[2] and a solitary specimen of *Penaeus canaliculatus* Olivier were collected. The presence of prawns in these pools was quite incidental.

During the initial stages of observation fairly large-sized prawns were available in good numbers. Prawns were relatively more in pools 1, 2 and 4 than in 3 and 5. It gives further evidence of the divergence in the nature of the pools as indicated by the hydrological and phytoplanktological characteristics discussed earlier. In pools 1 and 2 *Penaeus* spp. and in pool 3 *Metapenaeus* spp. were common. By that time intensive fishing was commenced by local people using all sorts of devices and the prawns started decreasing in numbers in the collections. From 2-3-1965 onwards only a few specimens occurred in the catches which were mainly composed of specimens of *Penaeus indicus*. By this time the water was nearing hypersalinity. It appears that *P. indicus* has a higher salinity tolerance than the other species of prawns met with in the pools. On 6-4-1965 it was found that almost all the prawns were dead in pool 1 and some of them were in a decayed condition, indicating their inability to survive in hypersaline water. Depletion of oxygen and the high heating during daytime might have also influenced it.

No progress in the modal length groups of prawns was observed. Besides constant fishing, the rigours of a unique environment where conditions change from one extreme to the other in quick succession would not have been congenial for growth processes of these animals as in their natural habitat.

Crabs : The crabs collected comprised of *Neptunus pelagicus* Linnaeus, which is a common species occurring in this area. They were also common in pools 1, 2 and 4 just as the prawns. The number of specimens present in different pools, their size range etc. are given in Table IV. They did not occur in catches from 30-3-1965 onwards. Later, many of them were found dead in the dried areas of pools 1, 2 and 4.

Other crustaceans collected included a few specimens of *Acetes* sp. and amphipods.

A few specimens of squid belonging to the genus *Sepioteuthis* were collected from pool 2.

A few nauplii were occasionally met with in the centrifuged samples. Tintinnids were very commonly found.

Fishes : Forty-six species of fish belonging to thirty-six genera and twenty-eight families have been collected during this study. All the species listed were not available on the first collection day ; a few occurred intermittently and certain other species only once either solitarily or in a few numbers. Even when a species

[1] This is the first record of this species from the east coast of India. The authors are thankful to Mr. M. J. George for the identification.

[2] A note on the occurrence of *M. lysianassa* in the south east coast of India is under publication by one of the authors (C.A.).

was collected on the last date of observation only, it is to be considered that the species concerned was present in the pool from the commencement of the studies since there was no scope for fresh entry. The non-availability of a species from a particular date onwards cannot be attributed to its inability to withstahd changes in the hydrological conditions since it could have been fished out. Only the occurrence of dead fish in the pools could indicate the lethal limits in the environmental conditions. A few such instances noted have been indicated in Table V wherein the data on the specimens collected viz., the last date of occurrence, total size range, and the total number obtained for each species have been presented poolwise.

An analysis of the data for the incidence of the different species showed 24 species in pool 1, 32 in pool 2, 21 in pool 3, 10 in pool 4 and 21 in pool 5. Out of the total number of 1914 specimens of all species collected from all the pools 550 (29%) fish from pool 1, 408 (21%) from pool 2, 237 (12%) from pool 3, 52 (3%) from pool 4 and 667 (35%) from pool 5 were available.

The fish met with in the collections were mostly young ones and almost coastal in habitat and in a few cases extending to estuaries, backwaters, tidal rivers and also fresh water. Out of the 46 species of fish, those which formed 1% and above in the total for all fish for all the pools and over the whole period are as follows : *Nematalosa nasus* and *Tilapia mossambica* were the most numerically abundant species forming 26% and 23% respectively. Next in the order were, *Liza macrolepsis* (14%) *L. parsia* (10%), *Leiognathus brevirostris* (7%), *Pelates quadrilineatus* (3%) *Gerres oyena* (2%), *Mugil cephalus* (1%) and *Torquigener oblongus* (1%). In a study of the ecological and fisheries characteristics of the salt water lagoon near Mandapam, Tampi (1959) stated that mullets (*Mugil* spp.), threadfin gizzard shad (*Nematalosa nasus*) and milkfish (*Chanos chanos*) are of fishery importance. The total absence of milkfish in the present collections possibly indicates its absence in the inshore waters in this area during the cyclone period. The presence of *Tilapia mossambica* in the pools, particularly its abundance in pool 5 which may be due to the fresh and brackish water environment it provided in the initial period of observation is noteworthy.

A total number of 24 species collected when salinity was above (41 ‰) that of sea water type have been listed in Table VI, wherein their state of occurrence (alive or dead) in the different salinity values have been mentioned. All the species listed seem to tolerate hypersaline conditions although a few dead specimens of *Thysanophyrs indicus* were noted ; but a few more seem to have survived and later died when salinity rose above 80‰. Quite a large number of species were found dead in salinity range of 81-87‰ ; only a few species survived in salinity above 87‰ *Liza macrolepis, L. parsia, Tilapia mossambica* and *Gerres abbreviatus* were the only species found alive in brine water ; however, a few specimens of *L. macrolepis* and *L. parsia* were found dead as also a few specimens of *Mugil cephalus*. Recently Durve and Alagarswami (1964) have reported mass mortality of fish, prawns, and clams in the shallow waters of Athankarai estuary and they have attributed the mortality of these animals to the excessive rise in salinity (96-97‰). In the present study the high salinity, diurnal variation of oxygen, particularly the pre-dawn minimum and the high afternoon temperature towards the later part of observation when the pools were very shallow would all have had their inimical influence on the survival of the fish.

Summary

1. Ecological study of populations in five pools at Mandapam formed as a result of the cyclone and tidal wave was conducted for over a three-month period.

2. Three pools with higher salinity and lower silicate content were colonised by *Peridinium* while two pools with lower salinity and higher silicate content were colonised by *Pyrocystis*, both causing bioluminescence in the pools.

3. All the pools showed clear succession of organisms with the progressive onset of summer and increase in salinity. Diatoms were succeeded by dinoflagellates in abundance and the climax of succession was marked by the appearance of flagellates belonging to either autotrophic Chlamydomonadineae or saprophytic Cryptomonadaceae.

4. Nine species of penaeid prawns, one species of crab, a few specimens of amphipods, and *Acetes* were the crustaceans collected. Size range, dominant size groups and total weight of the prawns are given. A few specimens of *Sepioteuthis* and a number of tintinnids were also recorded.

5. Forty-six species of fish which are mainly coastal in their habitat occurred in the pools. Size range, total number and the dates on which dead ones were noticed are given.

6. Twenty-four species of fish were found to tolerate hypersaline conditions of which four were found alive even in brine water (92‰).

7. The conditions in the pools were of a special nature. Salinity together with the diurnal variation of oxygen, with a pre-dawn minimum and the high temperature in the afternoon are considered as having affected the survival of the fauna consisting of fish, prawns and crabs.

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	Date	Salinity ‰	Oxygen ml/l	Phosphate µg. at. P/l	Silicate µg. at. Si/l	Temp. °C.	Depth (inches)
Pool 1	2-2-65	35.01	—	—	—	—	—
	9-2-65	40.30	0.784	2.50	33.33	25.6	27
	16-2-65	27.98	0.672	1.00	50.00	23.6	25
	23-2-65	34.92	0.112	0.40	50.00	24.5	23
	2-3-65	37.86	1.400	0.64	41.67	25.8	20
	9-3-65	41.82	0.952	0.91	50.00	25.1	15
	16-3-65	44.77	1.008	0.57	50.00	25.9	14
	23-3-65	55.51	1.736	0.34	29.41	27.0	12
	30-3-65	65.55	1.568	0.44	33.33	26.7	10
	6-4-65	77.29	0.952	0.14	41.67	27.6	—
	12-4-65	88.48	0.672	—	—	—	—
	20-4-65	75.59	—	—	—	27.0	—
	27-4-65	89.90	—	—	—	28.0	—
	5-5-65	124.66	—	—	—	28.4	—
	12-5-65	dried	—	—	—	—	—
Pool 2	2-2-65	36.07	1.904	0.45	—	—	—
	9-2-65	36.42	0.896	0.77	19.00	25.9	23.5
	16-2-65	33.43	2.576	0.10	29.55	24.1	26
	23-2-65	39.02	0 672	0.48	44.64	25.4	25
	2-3-65	41.46	1.568	0.61	55.56	26.0	19
	9-3-65	46.15	0.784	0.46	41.67	25.0	19
	16-3-65	53.89	1.036	0.33	45.46	26.0	14
	23-3-65	61.46	0.448	0.10	35.71	27.5	12
	30-3-65	71.15	Nil	0.20	71.43	26.9	13
	6-4-65	82.16	Nil	0.20	35.71	27.9	—
	12-4-65	91.72	Nil	—	—	—	—
	20-4-65	77.91	—	—	—	27.5	—
	27-4-65	89.09	—	—	—	28.1	—
	5-5-65	127.31	—	—	—	28.3	—
	12-5-65	dried	—	—	—	—	—
Pool 3	2-2-65	22.00	2.688	1.10	—	—	—
	9-2-65	22.71	0.672	1.00	32.05	26.5	21
	16-2-65	18.31	4.200	0.18	100.00	26.0	23
	23-2-65	19.72	0.728	0.67	41.67	26.5	21
	2-3-65	20.03	2.240	1.00	71.43	26.3	18
	9-3-65	21.47	1.232	0.57	41.67	25.5	18
	16-3-65	24.71	1.344	0.60	62.50	26.7	15
	23-3-65	28.85	0.728	0.13	100.00	28.0	11
	30-3-65	35.41	2.352	0.70	250.00	28.5	10
	6-4-65	46.06	1.288	0.39	125.00	28.6	—
	12-4-65	47.50	1.568	—	—	—	—
	20-4-65	55.98	—	—	—	28.0	—
	27-4-65	68.23	—	—	—	28.1	—
	5-5-65	77.51	—	—	—	28.5	—
	12-5-65	dried	—	—	—	—	—

TABLE I (*Contd.*)

	Date	Salinity ‰	Oxygen ml/l	Phosphate µg. at. P/l	Silicate µg. at. Si/l	Temp. °C.	Depth (inches)
Pool 4	2-2-65	30.44	3.528	0.82	—	—	—
	9-2-65	32.55	0.728	2.00	30.49	27.2	19
	16-2-65	30.27	2.800	0.18	31.25	24.4	22
	23-2-65	36.48	0.504	0.91	33.33	25.2	20
	2-3-65	40.57	0.672	0.67	31.25	26.0	13
	9-3-65	47.59	0.168	0.42	35.71	24.2	11
	16-3-65	63.80	Nil	0.42	41.67	25.1	16
	23-3-65	76.21	0.280	0.09	50.00	—	—
	30-3-65	107.97	Nil	0.30	100.00	28.5	—
	6-4-65	dried	—	—	—	—	—
Pool 5	2-2-65	19.54	3.920	1.04	—	—	—
	9-2-65	22.71	0.672	1.00	32.05	28.5	26
	16-2-65	20.07	4.480	0.34	108.33	25.1	25
	23-2-65	22.64	0.728	0.75	147.05	26.5	21
	2-3-65	23.44	2.128	1.38	100.00	26.4	20
	9-3-65	25.25	1.848	0.58	62.50	26.5	21
	16-3-65	28.49	2.128	0.35	71.43	25.1	16
	23-3-65	32.64	0.728	0.11	100.00	28.0	12
	30-3-65	38.30	1.680	0.35	125.00	29.0	12
	6-4-65	45.34	Nil	0.29	100.00	29.0	12
	12-4-65	51.65	1.400	—	—	—	—
	20-4-65	51.38	—	—	—	27.5	—
	27-4-65	57.19	—	—	—	28.6	—
	5-5-65	78.72	—	—	—	28.2	—
	12-5-65	72.06	—	—	—	28.4	—
	19-5-65	91.34	—	—	—	27.6	—
Lagoon	2-2-65	33.06	—	—	—	—	—
	9-2-65	36.25	3.248	0.96	12.50	25.4	—
	16-2-65	30.44	4.368	0.20	10.00	24.0	—
	23-2-65	37.07	1.400	2.00	20.00	24.4	—
	2-3-65	40.03	3.240	0.58	33.33	25.0	—
	9-3-65	46.51	1.904	0.43	38.46	24.0	—
	16-3-65	53.17	2.520	0.23	41.67	24.5	—
	23-3-65	64.88	2.408	0.11	27.78	26.0	—
	30-3-65	84.32	2.128	0.29	21.25	27.0	—
	6-4-65	107.61	2.128	0.20	15.00	27.6	—
	12-4-65	159.95	1.512	—	—	—	—
Palk Bay	2-2-65	28.51	—	—	—	—	—
	9-2-65	29.57	2.408	0.83	6.25	—	—
	16-2-65	29.04	4.704	0.44	17.50	25.5	—
	23-2-65	31.81	1.568	1.11	28.13	25.5	—
	2-3-65	29.58	4.312	0.67	38.46	26.0	—
	9-3-65	29.39	4.008	0.35	31.25	26.0	—
	16-3-65	29.75	3.808	0.25	31.25	26.5	—
	23-3-65	30.11	4.088	0.14	12.50	29.0	—
	30-3-65	31.44	4.032	0.45	10.00	27.0	—
	6-4-65	32.16	3.368	0.28	8.75	28.8	—
	12-4-65	32.70	3.248	—	—	—	—

TABLE II

Date	Species	Pools 1	2	3	4	5
2-2-1965	Dinophyceae ..	..	1,600	45,200	1,600	..
	Bacillariophyceae					
	Pleurosigma spp. ..	..	43,200	62,000	232,000	18,000
	Navicula spp. ..	..	1,360	3,200	3,600	6,000
	Others ..	..	2,000	3,600	800	2,800
9-2-1965	Dinophyceae ..	100,000	2,000	20,000	..	..
	Bacillariophyceae ..					
	Pleurosigma spp. ..	16,000	7,200	67,200	17,600	1,200
	Navicula spp. ..	2,000	4,400	4,000	2,400	1,200
	Others ..	1,200	400	1,600	..	800
16-2-1965	Dinophyceae ..	86,000	100,800	44,000	124,800	2,400
	Bacillariophyceae					
	Pleurosigma spp. ..	800	5,200	1,600	22,400	3,200
	Navicula spp. ..	..	4,800	1,200	4,000	3,600
	Others ..	..	..	3,600	..	800
23-2-1965	Dinophyceae ..	4,800	168,400	82,000	246,800	..
	Bacillariophyceae ..					
	Pleurosigma spp. ..	4,000	8,000	400	4,800	..
	Navicula spp. ..	4,000	4,800	..	400	2,800
	Others ..	..	400	400	1,600	2,000
2-3-1965	Dinophyceae ..	50,000	6,000	1,600	172,000	178,000
	Bacillariophyceae ..					
	Pleurosigma spp. ..	10,000	8,000	..	32,000	2,000
	Others ..	1,200	4,800	..	800	1,600
9-3-1965	Dinophyceae ..	400,000	12,800	..	133,000	241,000
	Bacillariophyceae ..					
	Pleurosigma spp. ..	8,000	4,000	..	28,000	1,600
	Navicula spp. ..	800	2,000	..	2,000	400
	Others ..	..	1,600	..	1,600	400
16-3-1965	Dinophyceae ..	38,800	48,000	800	89,000	280,000
	Bacillariophyceae ..					
	Pleurosigma spp. ..	5,600	3,200	800	2,800	800
	Navicula spp. ..	400	..	400	..	..
	Flagellates .. (Chlamydomonadineae—*Carteria*) ..	..	..	..	26,000,000	..

TABLE II (*Contd.*)

Date	*Species*	*Pools* 1	2	3	4	5
15-3-1965	Dinophyceae	8,000	125,200	..	..	276,000
	Bacillariophyceae ..					
	Pleurosigma spp. ..	3,200	400	..	4,000	400
	Navicula spp. ..	1,200	..	..		2,800
	Others	400	..	400	..	..
	Flagellates (Chlamydomonadineae—*Carteria*)	..	..	..	30,000,000	..
30-3-1965	Dinophyceae	5,200	6,800	..	..	140,000
	Bacillariophyceae ..					
	Pleurosigma spp. ..	400	1,600	1,500	..	3,600
	Navicula spp. ..	400	..	1,200	..	87,200
	Others	..	..	4,000	800	400
	Flagellates .. .. (Chlamydomonadineae—*Carteria*)	..	..	..	40,000,000	..
7-4-1965	Dinophyceae	800	1,200	..	..	200,000
	Bacillariophyceae ..					
	Pleurosigma spp. ..	800	4,400	..	..	2,800
	Navicula spp. ..	400	..	..	..	24,000
	Others	..	..	..	..	1,200
	Flagellates					
	1. Chlamydomonadineae—*Carteria*	18,000,000	..	..	..	..
	2. Chryptomonadaceae—*Chilomonas* ..	..	1,200,000		..	..

TABLE III

Date	Species*	Pool 1				Pool 2				Pool 3				Pool 4				Pool 5			
		No. of specimens	Size range in mm.	Dominant size group in mm.	TOTAL WEIGHT	No. of specimens	Size range in mm.	Dominant size group in mm.	TOTAL WEIGHT	No. of specimens	Size range in mm.	Dominant size group in mm.	TOTAL WEIGHT	No. of specimens	Size range in mm.	Dominant size group in mm.	TOTAL WEIGHT	No. of specimens	Size range in mm.	Dominant size group in mm.	TOTAL WEIGHT
2-2-1965	*Penaeus indicus*	42	95-120	111-115	1,463 gms.	..	..	..	198 gms.	18	51-66	56-60	49 gms.	..	..	..	380 gms.	21	60-85	71-75	100 gms.
	P. merguiensis	92	55-126	111-115		21	66-112	91-95		9	45-101	46-50		52	48-74	61-65		9	54-105	56-60	
	P. semisulcatus	24	49-125	101-105		11	40-106	41-45		8	42-54	..		73	48-99	61-65		11	41-90	41-45	
	Metapenaeus affinis	34	30-78	56-60		3	48-66	..		10	27-44	36-40		255	29-56	36-40		27	26-52	31-35	
	M. dobsoni	6	26-65	31-35		..	..	..		..	..	..		50	29-79	31-35		..	..	..	
9-2-1965	*P. indicus*	3	66-75	71-75	457 gms.	2	94-106	..	266 gms.	24	48-88	56-60	73 gms.	33	53-89	81-85	345 gms.	3	75-85	..	53 gms.
	P. merguiensis	15	56-120	56-60		14	45-112	101-105		19	44-102	51-55		32	51-107	61-65		5	60-102	..	
	P. semisulcatus	38	52-126	111-115		87	37-93	46-50		12	43-62	46-50		1	56	..		3	56-110	..	
	P. monodon	..	..	..		..	..	..		..	..	..		..	..	..		1	76	..	
	M. affinis	23	38-84	36-40		8	40-73	51-55		38	21-55	31-35		209	32-66	36-40		1	56	..	
	M. dobsoni	..	..	..		..	..	..		..	..	..		26	48-59	51-55		..	..	..	
19-2-1965	*P. indicus*	16	61-104	71-75	196 gms.	7	89-122	..	94 gms.	59	56-74	61-65	96 gms.	11	55-81	71-75	228 gms.	4	54-66	..	60 gms.
	P. merguiensis	2	62-92	..		3	77-95	..		2	46-55	..		4	51-66	51-55		8	80-103	91-95	
	P. semisulcatus	14	45-77	51-55		3	51-101	..		5	61-69	65-16		..	..	..		..	..	..	
	P. monodon	3	72-138	71-75		..	..	..		1	115	..		..	..	..		1	102	..	
	M. affinis	62	32-71	41-45		15	52-68	61-65		4	37-64	61-65		203	31-52	41-45		..	..	..	
	M. dobsoni	15	41-69	56-60		1	68	..		..	..	..		1	58	..		..	..	..	

23-2-1965	P. i[illegible]	21	66-118	89-90	217 gms.	62	58-112	71-75	246 gms.	31	56-80	61-65	57 gms.	13	70-92	76-80	49 gms.	2	55-60	..	4 gms.
	[illegible]	13	61-117	76-80		..	..	..		..	..	..		1	66	..		..	..	..	
	P. se[illegible]tus	5	53-80	56-60		..	..	..		..	..	..		..	..	..		..	..	..	
	P. monodon	1	70	..		..	..	..		..	..	..		..	..	..		..	..	..	
	M. affinis	63	32-71	41-45		15	52-62	56-60		1	49	..		11	39-44	41-45		..	..	..	
	M. dobsoni	15	41-63	56-60		1	63	..		..	..	..		..	..	..		..	..	..	
2-3-1965	P. indicus	39	64-101	76-80	138 gms.	29	69-114	81-85	160 gms.	50	52-74	61-65	95 gms.	3	66-77	..	379 gms.	5	51-59	..	7 gms.
	P. affinis	3	45-48	46-50		..	..	..		..	..	..		467	38-51	41-4		..	..	..	
9-3-1965	P. indicus	97	51-109	81-85	120 gms.	25	69-104	81-85	134 gms.	5	59-66	61-65	25 gms.	..	..	..	17 gms.	..	..	..	
16-3-1965	P. indicus	8	73-100	91-95	35 gms.	5	91-128	91-95	46 gms.	56	55-81	56-60	113 gms.	..	..	..		2	60-62	..	4 gms.
	P. monodon	..	..	..		1	90	..													
23-2-1965	P. indicus	14	76-90	86-90	76 gms.	1	98	..	4 gms.	22	55-68	61-65	36 gms.	..	..	..		2	56-62	..	5 gms.
30-3-1965	P. indicus	13	71-89	86-90	72 gms.	3	90-113	..	13 gms.	..	..	..		..	..	..		..	..	..	

* Only the species available on the date of collection has been mentioned.

TABLE IV

Date	Pool-1		Pool-2		Pool-3		Pool-4		Pool-5	
	No. of specimens	Size range in mm.	No. of specimens	Size range in mm.	No. of specimens	Size range in mm.	No. of specimens	Size range in mm.	No. of specimens	Size range in mm.
2-2-1965	12	29-41	—	—	1	71	38	31-53	4	29-43
9-2-1965	1	35	7	21-87	2	41-49	8	31-42	2	42-51
16-2-1965	11	25-44	5	31-64	3	31-70	12	35-66	—	—
23-2-1965	9	23-41	15	28-52	—	—	10	35-60	—	—
2-3-1965	11	31-51	1	33	1	54	8	41-64	1	40
9-3-1965	14	32-58	—	—	—	—	6	40-51	—	—
16-3-1965	7	32-75	6	34-40	1	66	15	38-55	—	—
23-3-1965	2	39-47	1	34	—	—	—	—	—	—

TABLE V

Pool No.* (1)	Last date of occurrence (2)	Total size range (T.L. in mm.) (3)	Total No. of specimens collected over the whole period (4)
	Elops machnata (Forskal)		
2.	9-2-1965	122-170	6
3.	23-2-1965	122,140	2
	Megalops cyprinoides (Broussonet)		
3.	23-3-1965	130,170	2
5.	20-4-1965	180,181	2
	Nematalosa nasus (Bloch)		
1.	9-2-1965	23-72	182
2.	30-3-1965	24-94	124
3.	23-3-1965	60-94	46
4.	9-2-1965	23-82	7
5.	16-2-1965	32-68	146
	Anchoviella indica (Van Hasselt)		
2.	16-2-1965	72	1
	Anchoviella baganensis (Hardnberg)		
2.	9-2-1965	98	1
	Mystus gulio (Hamilton-Buchanan)		
1.	2-2-1965	84,107	2
3.	30-3-1965	112	1
4.	16-3-1965	91	1
5.	20-4-1965	61-159	10
	Tylosurus strongylurus (Van Hasselt)		
2.	9-3-1965	235	1
	Hemirhamphus dussumieri Cuvier & Valenciennes		
2.	23-3-1965	144	1
	Corythoichthys fasciatus (Gray)		
1.	2-3-1965	92	1
2.	23-2-1965	109-130	3
	Mugil cephalus Linnaeus		
1.	30-4-1965	104-121	3
	*12-4-1965	106-152	9
3.	12-4-1965	50-115	16
	Mugil cunnesius Valenciennes		
3.	2-3-1965	92	1
	Liza macrolepis (Smith)		
1.	27-4-1965	30-90	140
	*12-4-1965	65-90	8
2.	27-4-1965	39-94	24
	*27-4-1965	87,106	2
3.	27-4-1965	57-104	55
5.	19-5-1965	52-114	37

* Only the pool wherein the species of fish was available has been mentioned.

TABLE V (*Contd.*)

(1)	(2)	(3)	(4)
	Liza parsia (Hamilton-Buchanan)		
1.	27-4-1965	28-99	31
	*12-4-1965	63,80	2
2.	20-4-1965	64-125	42
3.	20-4-1965	57-139	81
5.	19-5-1965	68-124	25
	Ellochelon waigiensis (Quoy and Gaimard)		
1.	30-3-1965	94	1
2.	2-2-1965	51	1
5.	20-4-1965	41-66	16
	Pranesus duodecimalis (Valenciennes)		
2.	2-2-1965	59, 76	2
4.	9-2-1965	64	1
	Eleutheronema tetradactylum (Shaw)		
1.	2-2-1965	74, 74	2
3.	9-3-1965	107-153	5
5.	16-2-1965	89	1
	Ambassis gymnocephalus (Lacépède)		
3.	23-3-1965	48	1
4.	16-2-1965	43	1
5.	5-5-1965	42-49	12
	Epinephelus tauvina (Forskal)		
3.	9-3-1965	165	1
	Pelates quadrilineatus (Bloch)		
2.	9-3-1965	22-61	45
	*6-4-1965	55-85	16
4.	9-2-1965	50	1
	Autisthes puta (Cuvier)		
2.	30-3-1965	34-68	4
	*6-4-1965	48-84	11
4.	9-2-1965	74	1
	Therapon jarbua (Forskal)		
1.	*12-4-1965	87-107	3
2.	*6-4-1965	88-120	8
3.	23-2-1965	86	1
5.	2-2-1965	65	1
	Carangoides praeustes (Bennett)		
1.	9-2-1965	36-63	6
3.	2-3-1965	74-102	4
5.	2-2-1965	45	1
	Gerres oblongus Cuvier		
2.	30-3-1965	62, 71	2
	*6-4-1965	74	1
5.	23-2-1965	43-45	3
	Gerres abbreviatus Bleeker		
1.	12-4-1965	74, 77	2
2.	23-3-1965	83	1
5.	2-2-1965	47, 75	2

TABLE V (*Contd.*)

(1)	(2)	(3)	(4)
	Gerres oyena (Forskal)		
2.	30-3-1965	35-63	30
	*6-4-1965	78	1
3.	23-2-1965	47	1
5.	16-3-1965	49, 55	2
	Secutor insiditor (Bloch)		
1.	2-2-1965	83	1
	Secutor ruconius (Hamilton-Buchanan)		
1.	2-2-1965	37-60	3
	Leiognathus splendens (Cuvier)		
1.	2-2-1965	34, 45	2
2.	23-2-1965	33-45	4
5.	16-2-1965	34-44	5
	Leiognathus brevirostris (Valenciennes)		
1.	9-2-1965	32-79	91
2.	9-3-1965	31-69	9
3.	16-3-1965	30-78	11
4.	9-2-1965	35-39	12
5.	16-2-1965	22-69	19
	Pomadasys hasta (Bloch)		
1.	9-2-1965	58-77	8
2.	16-2-1965	47-78	12
3.	23-3-1965	80-96	4
5.	16-2-1965	50, 60	2
	Scatophagus argus (Linnaeus)		
2.	2-2-1965	37	1
	Tilapia mossambica (Peters)		
1.	12-4-1965	58-124	12
2.	27-4-1965	38-154	31
3.	23-2-1965	71	1
4.	16-3-1965	12-185	25
5.	19-5-1965	15-145	373
	Dasson variabilis Cantor		
1.	9-2-1965	75	1
2.	16-2-1965	71-83	4
	Dasson Sp.		
2.	2-2-1965	65, 83	2
	Callionymus schaapi Bleeker		
1.	9-2-1965	77, 77	2
	Ctenogobius nebulosus (Forskal)		
2.	16-3-1965	65	1
	Ctenogobius sp.		
1.	16-3-1965	38-63	7
2.	9-3-1965	36-40	5
3.	9-2-1965	25	1
4.	23-2-1965	27	1
	Grammoplites scaber (Linnaeus)		
2.	2-3-1965	60	1

TABLE V (*Contd.*)

(1)	(2)	(3)	(4)
	Thysanophrys indicus (Linnaeus)		
1.	9-3-1965	111	1
	*6-4-1965	67-140	5
2.	*6-4-1965	98-163	6
4.	2-2-1965	78	1
5.	2-2-1965	76	1
	Pseudorhombus javanicus (Bleeker)		
3.	2-3-1965	108	1
	Grammatobothus sp.		
2.	16-2-1965	44	1
	Pseudotriacanthus strigiliger (Cantor)		
1.	9-2-1965	55	1
	Triacanthus brevirostris Schlegel		
1.	9-2-1965	45-55	7
2.	16-2-1965	77	1
4.	9-2-1965	(mutilated)	1
5.	16-2-1965	35-49	4
	Triacanthus biaculeatus (Bloch)		
2.	*6-4-1965	53	1
3.	23-3-1965	42	1
5.	16-2-1965	40	1
	Torquigener oblongus (Bloch)		
1.	2-2-1965	46-75	17
2.	16-2-1965	62, 62	2
5.	16-2-1965	55, 60	3
	Arothron leopardus (Day)		
3.	23-2-1965	60	1

* Date of occurrence of dead fish.

TABLE VI

[illegible]of 24 species of fish in different ranges (41‰-92‰) of salinity

Species	41-60‰ D	41-60‰ A	61-80‰ D	61-80‰ A	81-87‰ D	81-87‰ A	88-92‰ D	88-92‰ A
1. *Megalops cyprinoides*	—	A	—	—	—	—	—	—
2. *Nematalosa nasus*	—	A	—	A	—	—	—	—
3. *Mystus gulio*	—	A	—	—	—	—	—	—
4. *Tylosurus strongylurus*	—	A	—	—	—	—	—	—
5. *Hemirhamphus dussumieri*	—	—	—	A	—	—	—	—
6. *Corythoichthys fasciatus*	—	A	—	—	—	—	—	—
7. *Mugil cephalus*	—	—	—	A	—	—	D	—
8. *Liza macrolepis*	—	A	—	A	—	A	D	A
9. *L. parsia*	—	A	—	A	—	A	D	A
[illegible]*llochelon waigiensis*	—	A	—	A	—	—	—	—
[illegible]*bassis gymnocephalus*	—	A	—	A	—	—	—	—
[illegible]*ates quadrilineatus*	—	A	—	—	D	—	—	—
[illegible]*isthes puta*	—	—	—	A	D	—	—	—
[illegible]*apon jarbua*	—	—	—	—	D	—	D	—
[illegible]*res oblongus*	—	—	—	A	D	—	—	—
[illegible]*bbreviatus*	—	—	—	A	—	—	—	A
[illegible]*yena*	—	A	—	A	D	—	—	—
[illegible]*nathus brevirostris*	—	A	—	—	—	—	—	—
[illegible]*pia mossambica*	—	A	—	A	—	—	—	A
20. *Ctenogobius nebulosus*	—	A	—	—	—	—	—	—
21. *Ctenogobius* sp.	—	A	—	—	—	—	—	—
22. *Grammoplites scaber*	—	A	—	—	—	—	—	—
23. *Thysanophrys indicus*	—	A	D	—	D	—	—	—
24. *Triacanthus biaculeatus*	—	—	—	—	D	—	—	—

D—Dead, A—Alive.